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Beyond Pipes to Watersheds Research Based Stormwater System Design

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Beyond Pipes to Watersheds

Research Based Stormwater System Design

November, 2014

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CICEET

Agenda

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Introduction

Stormwater Control Measures – at the end of the pipe

Site Level Case Studies

Watershed Level Case Studies

Not –so-emergent Issues

Discussion

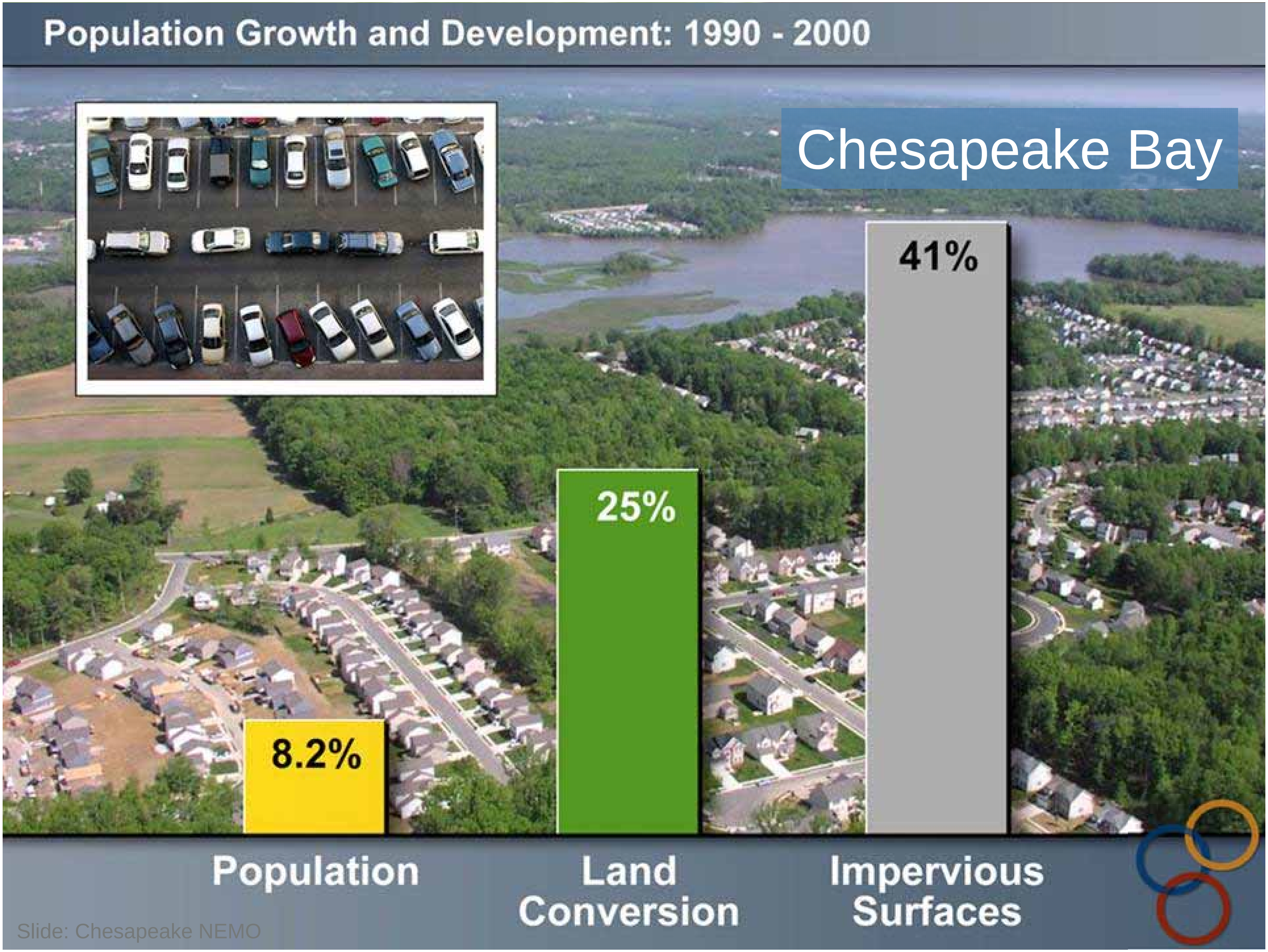
University of New Hampshire Stormwater Center

Providing Data to Protect Water Quality Since 2004

What's the big deal?

Where are we today?

- **Point-source technology based standards have largely been successful.**
- **Water quality-based standards (nonpoint source) have been difficult to achieve and enforce.**


Population Growth and Development: 1990 - 2000
Chesapeake Bay
41%
25%
8.2%
Population
Land Conversion
Impervious Surfaces
Slide: Chesapeake NEMO

Land Conversion in the Great Bay

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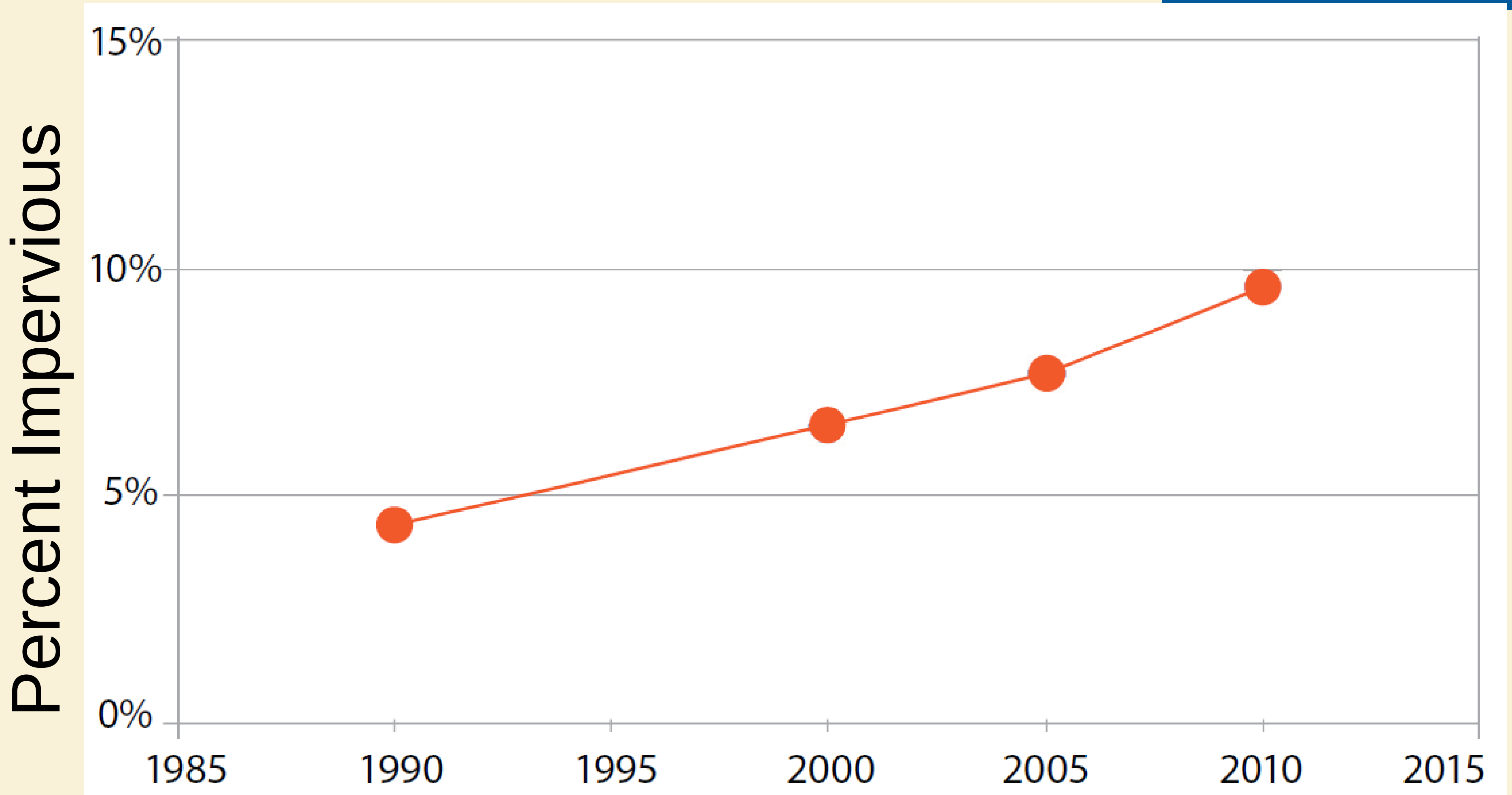
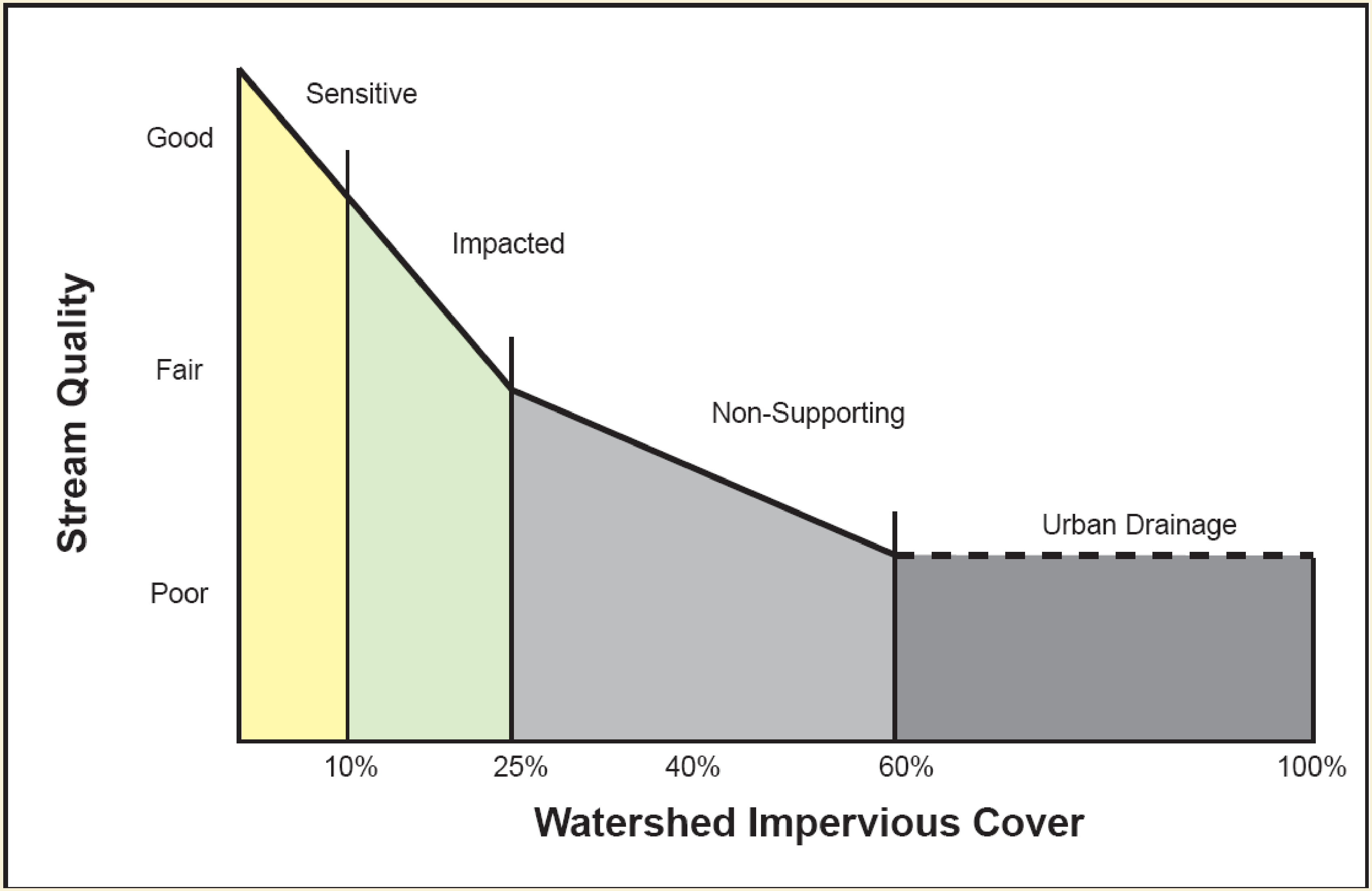
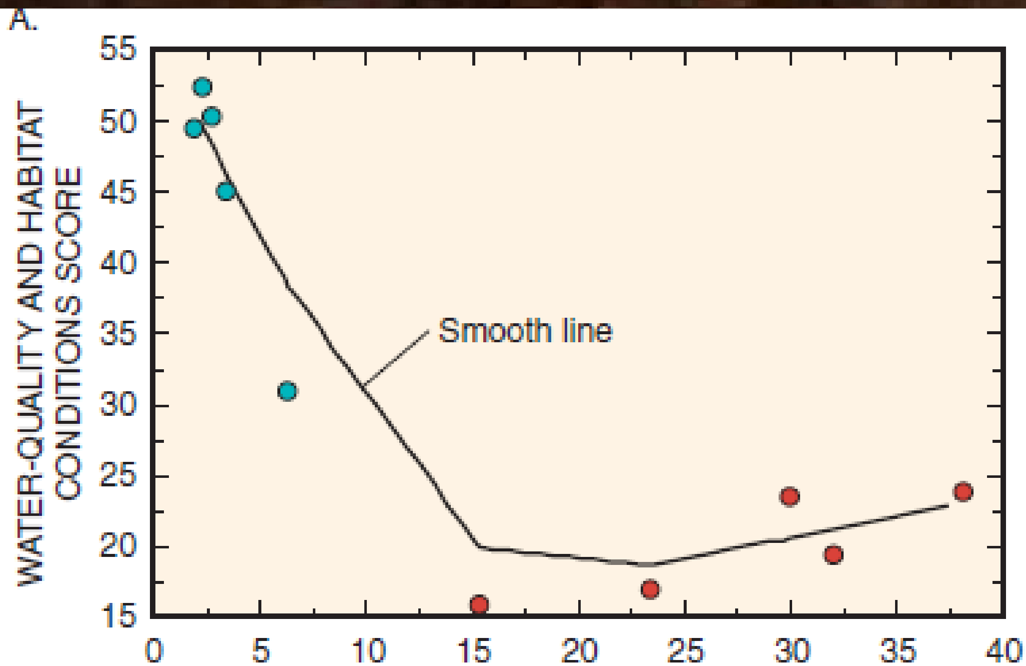


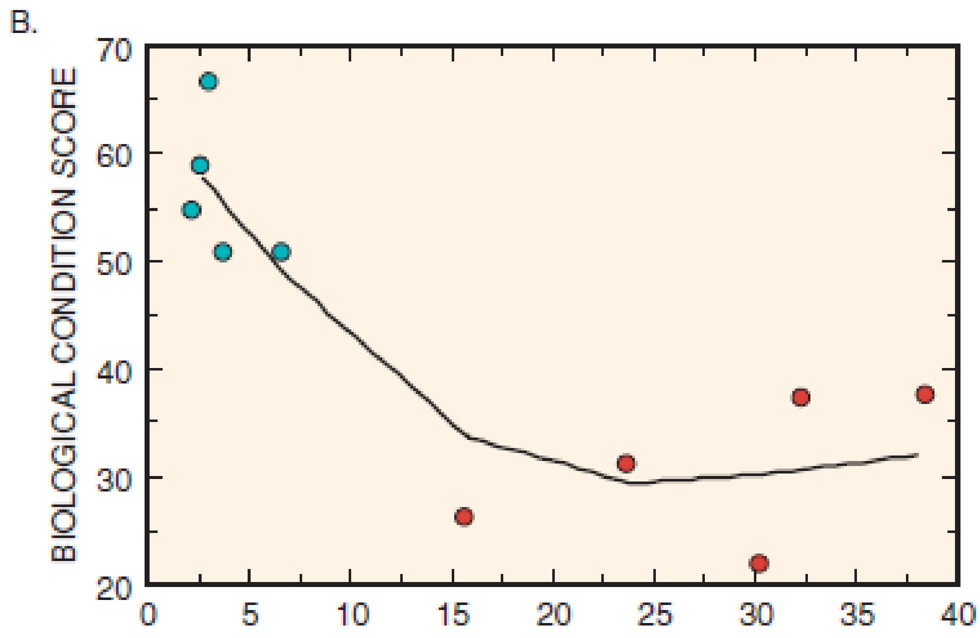
UNH earth systems research center (GRANIT)/ PREPP

Impact of Impervious Cover

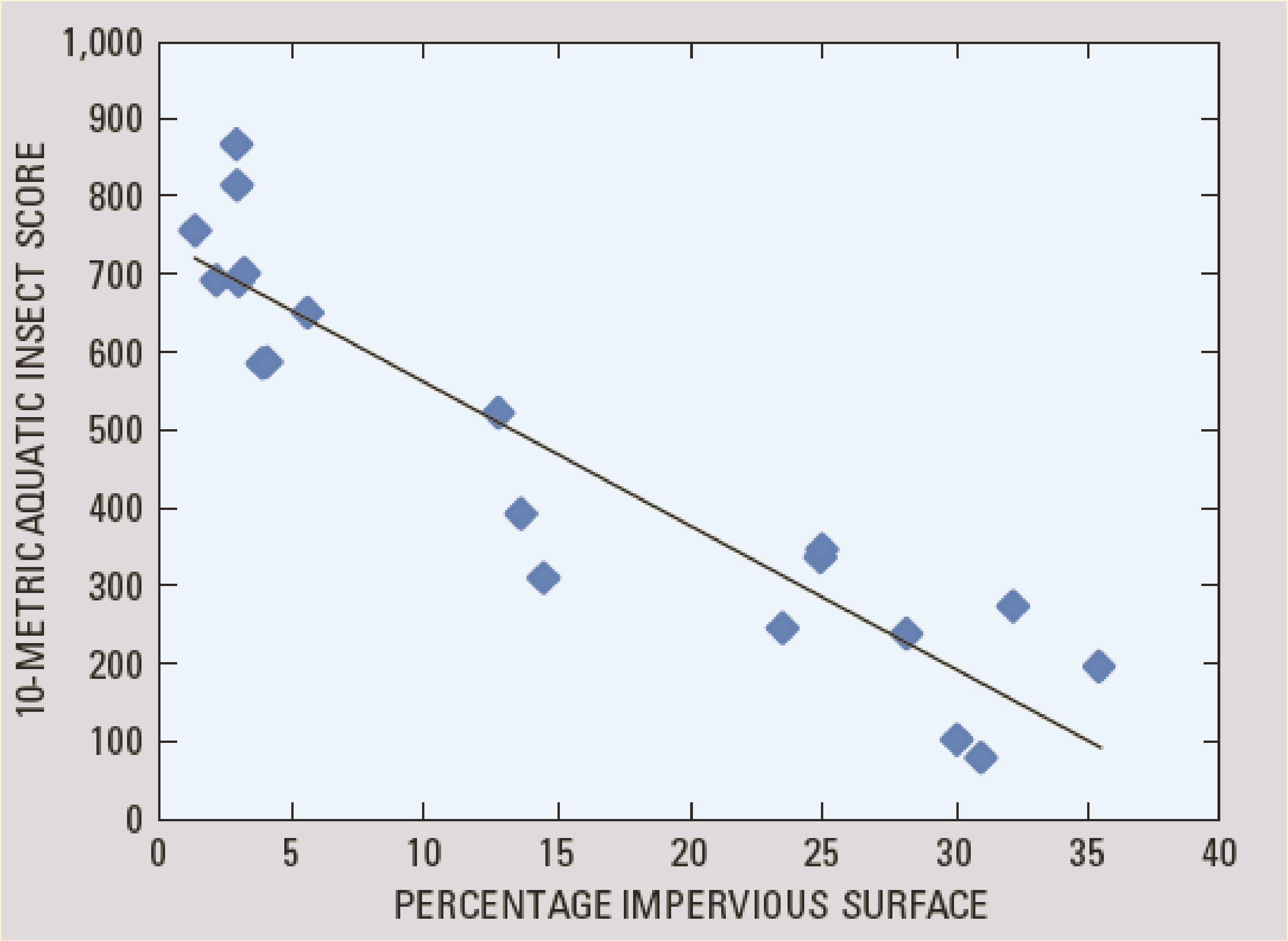


Adapted from Schueler

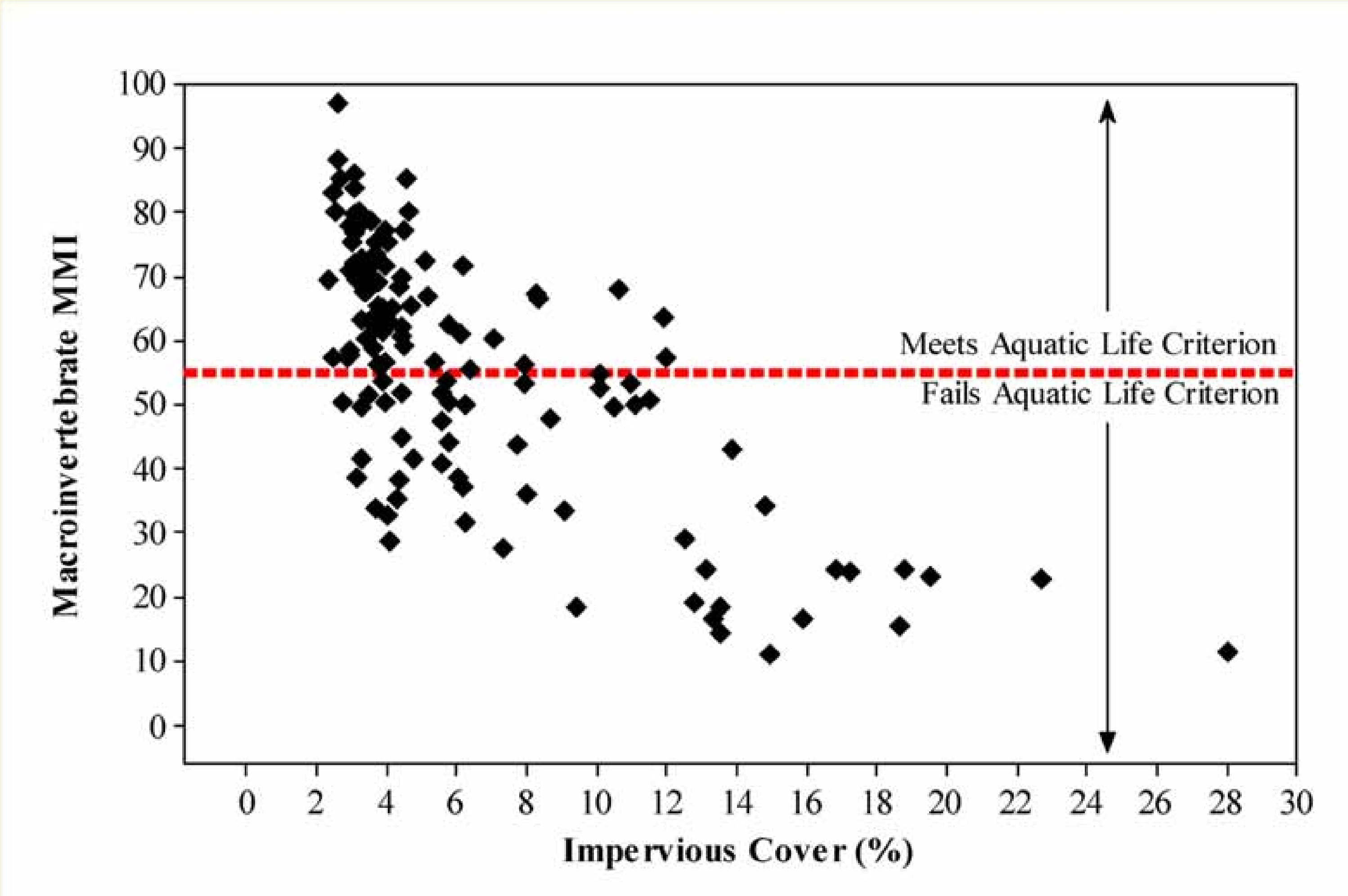




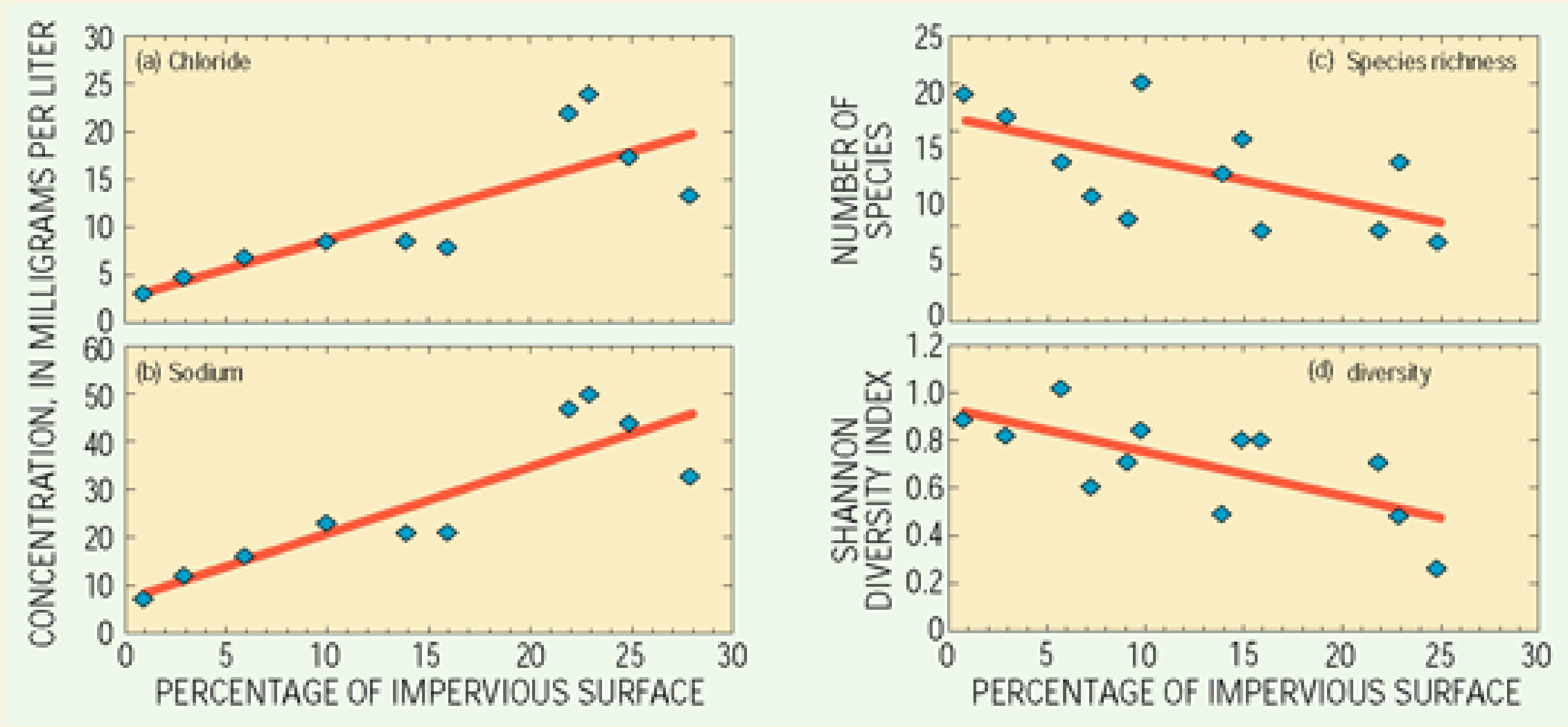
Source: Effects of Urbanization on Stream Quality at Selected Sites in the Seacoast Region in New Hampshire, 2001-03, USGS 2005



Rasmussen, T.J., Poulton, B.C., and Graham, J.L., 2009



Bellucci, Becker, and Beauchene, 2011



Stark, Hanson, Goldstein, Fallon, Fong, Lee, Kroening, and Andrews, 2000

Why We're Here

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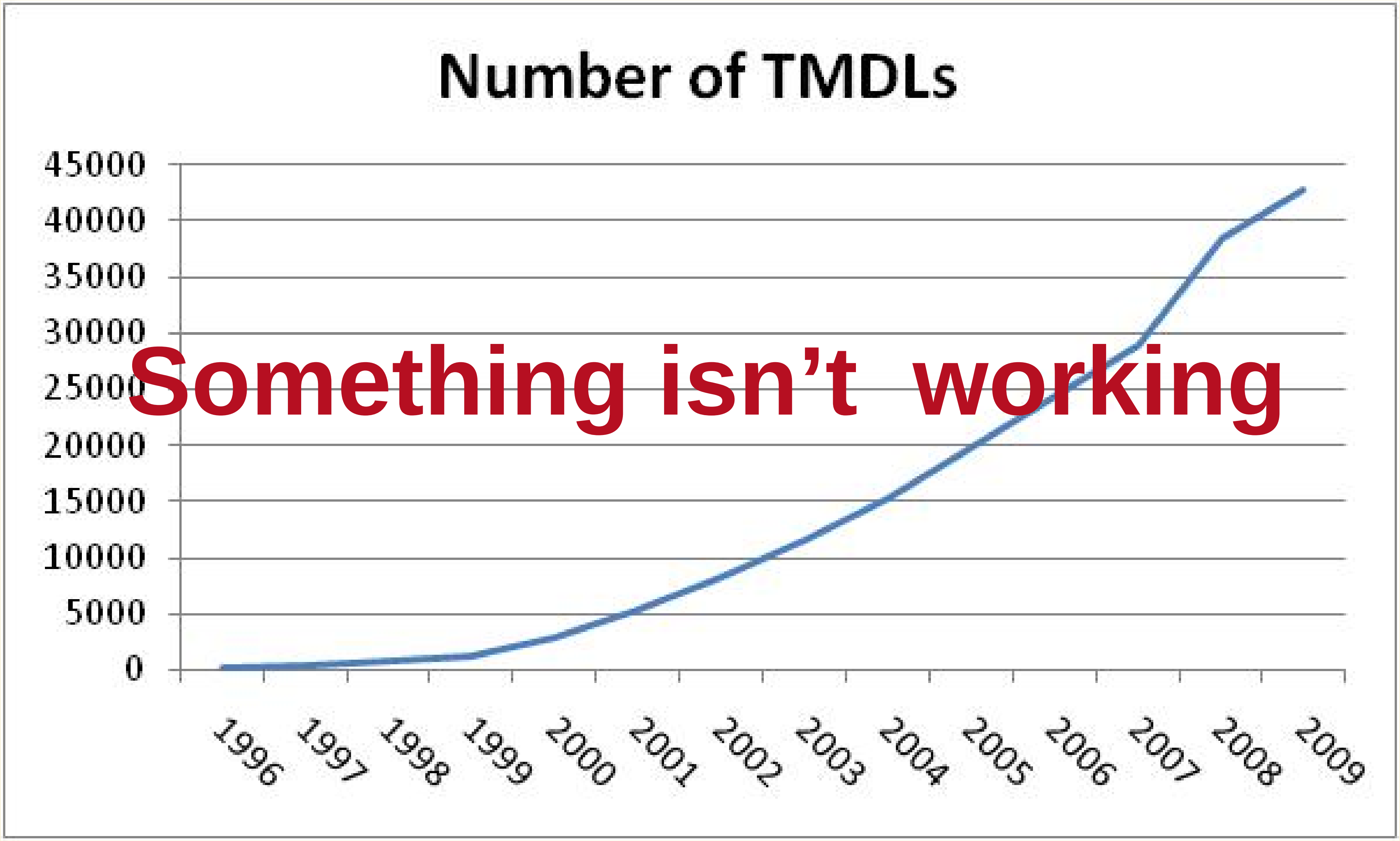
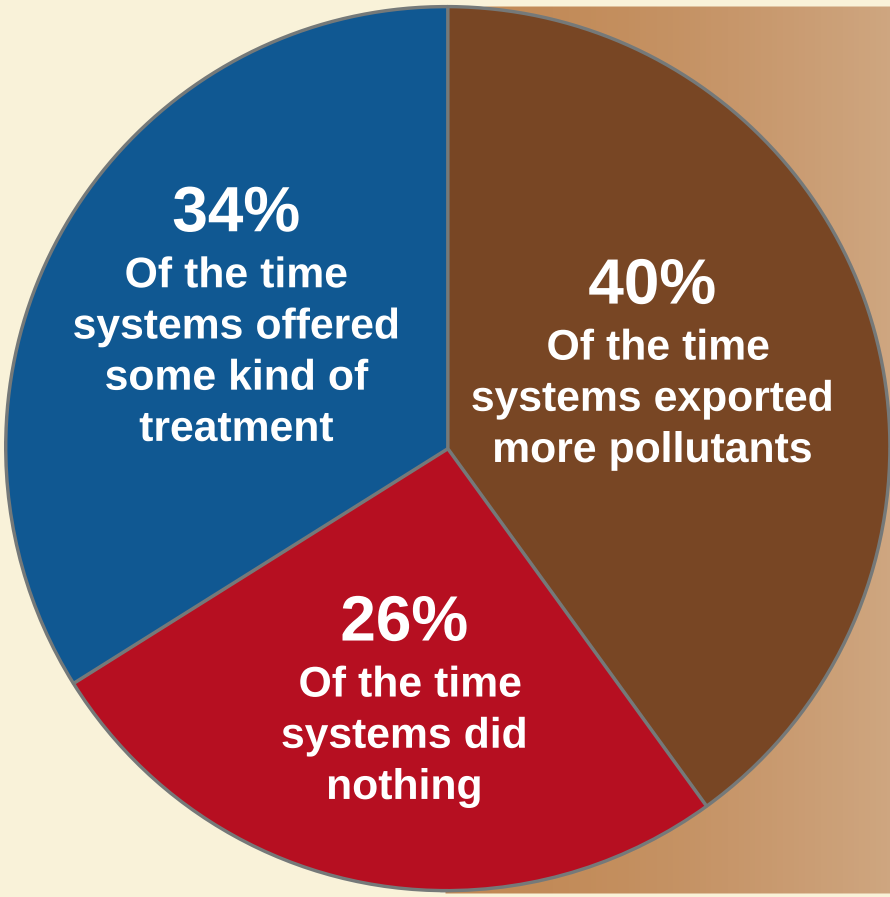


Something isn't working

Why the Center Was Created

Three-Year Study of Conventional Systems

Study Found That…



Systems failed 2/3 of the time!

BMP Performance Monitoring

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Research Field Facility at UNH

Tc ~ 19 minutes

BMP Performance Monitoring

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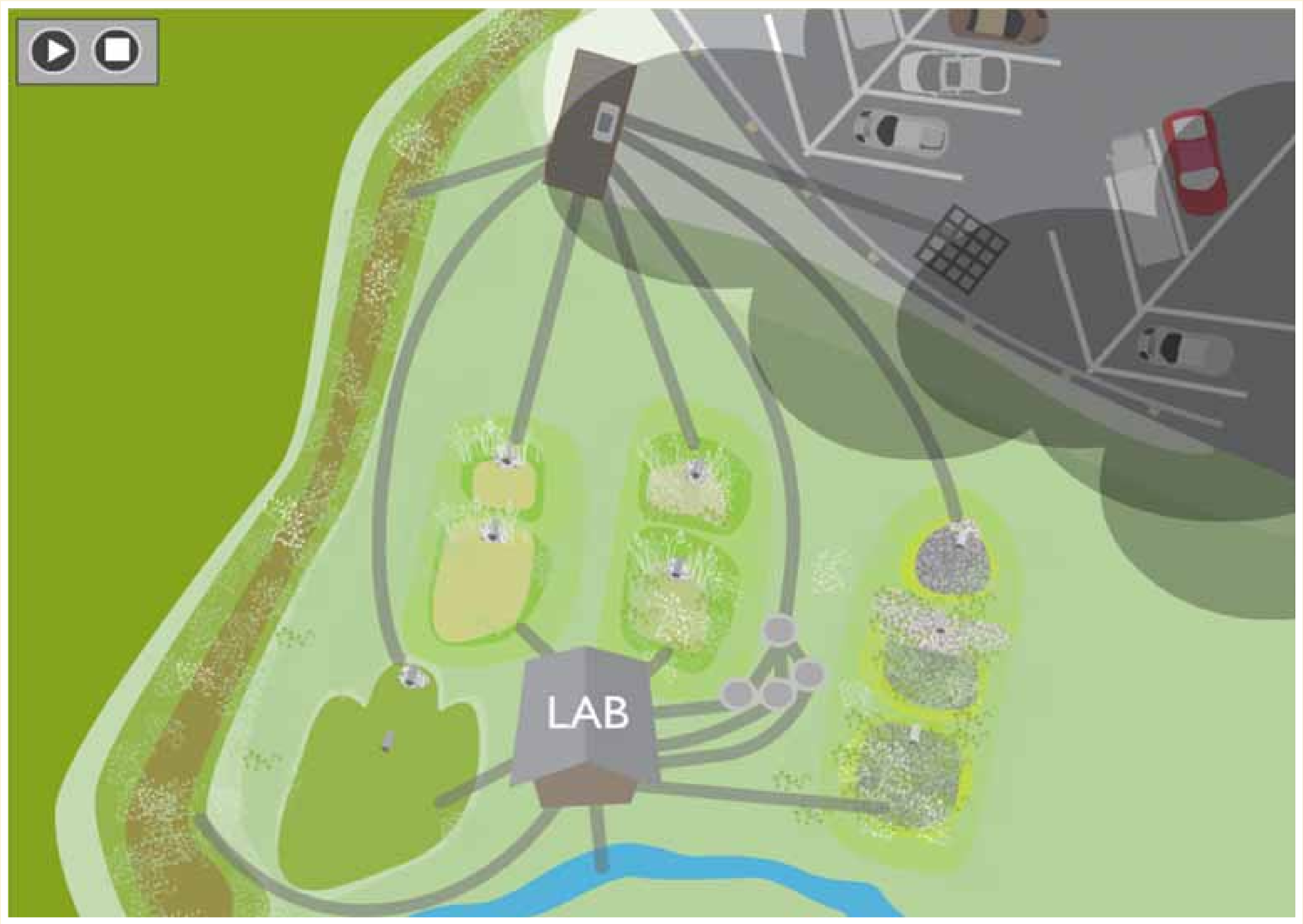

BMP Performance Monitoring

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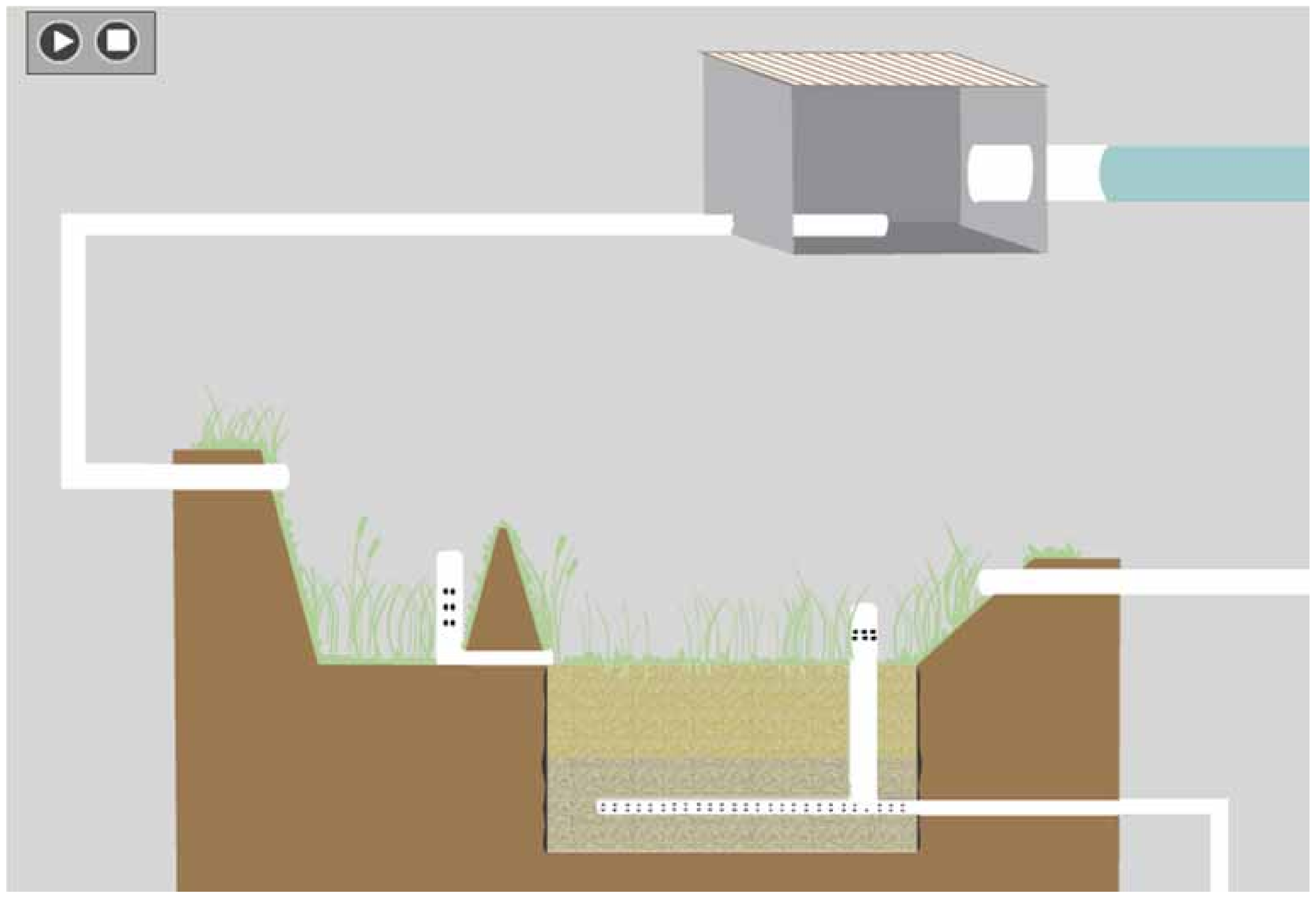
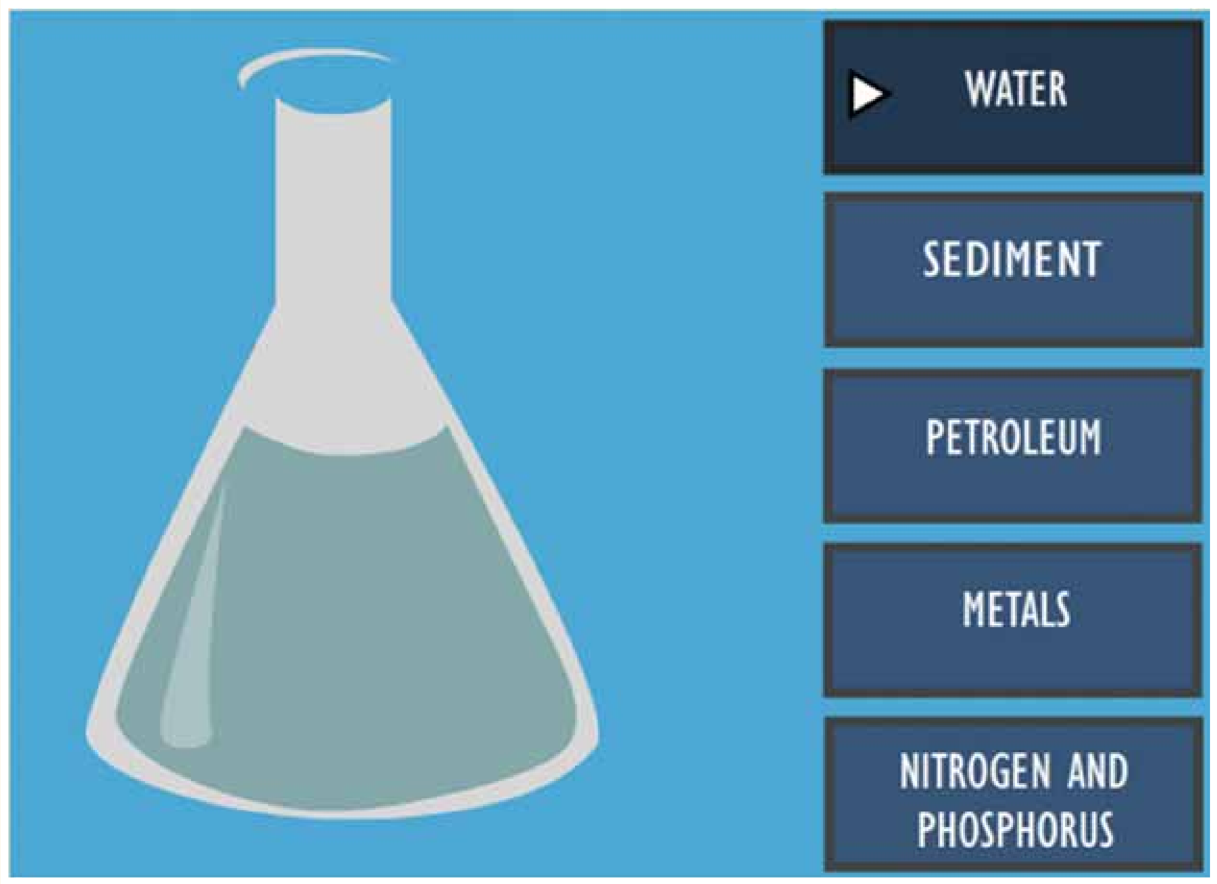
How We Evaluate Systems



What We Look For



What We Do: Outreach

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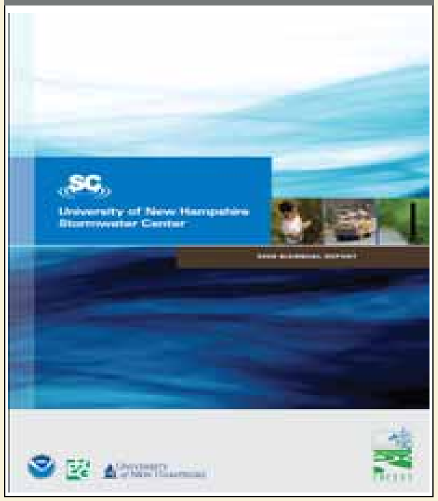
Data Reports

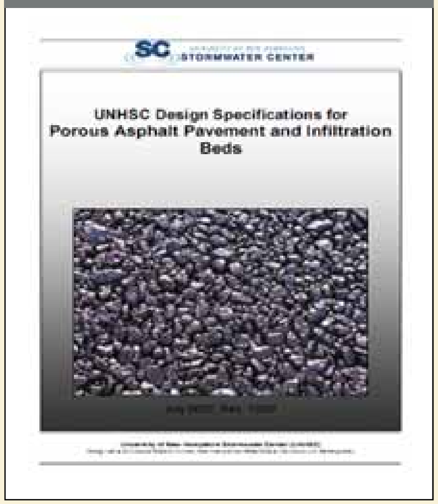


Web Resources

BMP Fact Sheets

Workshops

Design Specs



Journal Articles

Stormwater Outreach Can Be Challenging

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Because we don't always speak the same language

Swale Retention Pond Permeable Interlocking Concrete Pavers Detention Pond

Permeable Interlocking Concrete Pavers

Subsurface Detention Permeable Interlocking Concrete Pavers Water Quality Inlet

Permeable Interlocking Concrete Pavers

Downstream Defender Bio-Swale Naturalized Basin

Permeable Interlocking Concrete Pavers

Permeable Interlocking Concrete Pavers

Storm Trooper Vort-Sentry V2B1 Bay Saver

Permeable Interlocking Concrete Pavers

Permeable Interlocking Concrete Pavers

Bioretention Rain Garden Tree Filter Filtera

Permeable Interlocking Concrete Pavers

Permeable Interlocking Concrete Pavers

Sand Filter Delaware Austin ADS StormTech

Permeable Interlocking Concrete Pavers

Gravel Wetland Stormwater Wetland Surface Wetland

Permeable Interlocking Concrete Pavers

Permeable Interlocking Concrete Pavers

Pervious Concrete Porous Asphalt Constructed Wetland

Imagine the Ultimate System…

Now Consider Bioretention

No Need to Reinvent this Wheel

Use Unit Operations & Processes (UOPs)

- Physical Operations
- Biological Processes
- Chemical Processes
- Hydrologic Operations

Physical UOPs

Sedimentation

Enhanced Sedimentation

Filtration

Screening

Biological UOPs

Vegetative Process

Microbial Process

Chemical UOPs

Sorption

Antibacterial

Flocculation

Coagulation

Hydrologic UOPs

Flow Alteration

Volume Reduction

Using UOPs to Meet Your Challenges

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Number of UOPs that can solve ALL of your problems:

0

Combining UOPs within Systems

Pollutant 1

Pretreatment/
Primary
Treatment

Pollutant 2

Secondary
Treatment

Pollutant 3

Tertiary
Treatment

Systems We Will Cover

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- Bioretention systems/TBF
- Subsurface gravel wetland
- Pervious pavements

Bioretention Systems

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tree filters	bioretention
	

Bioretention System Design

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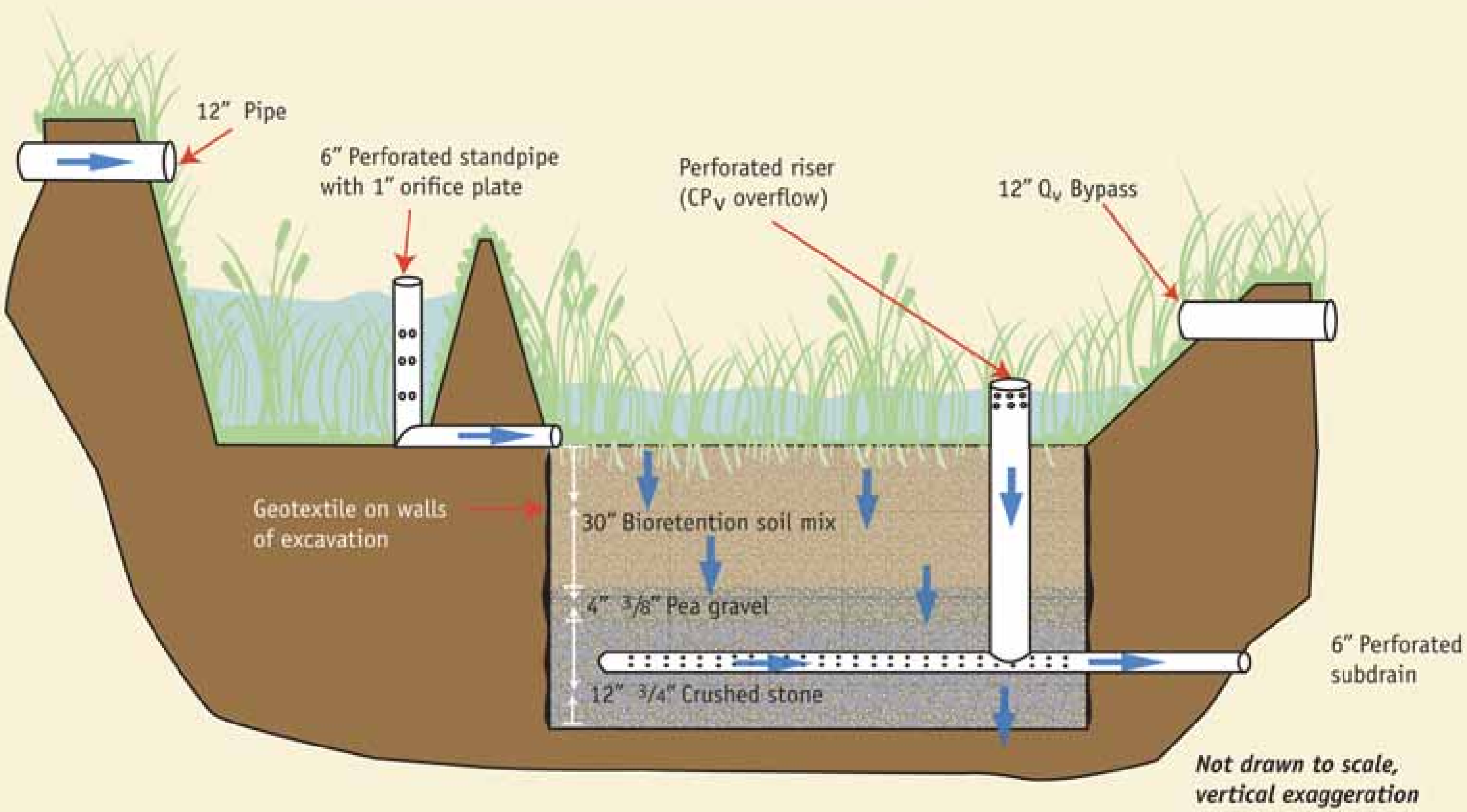
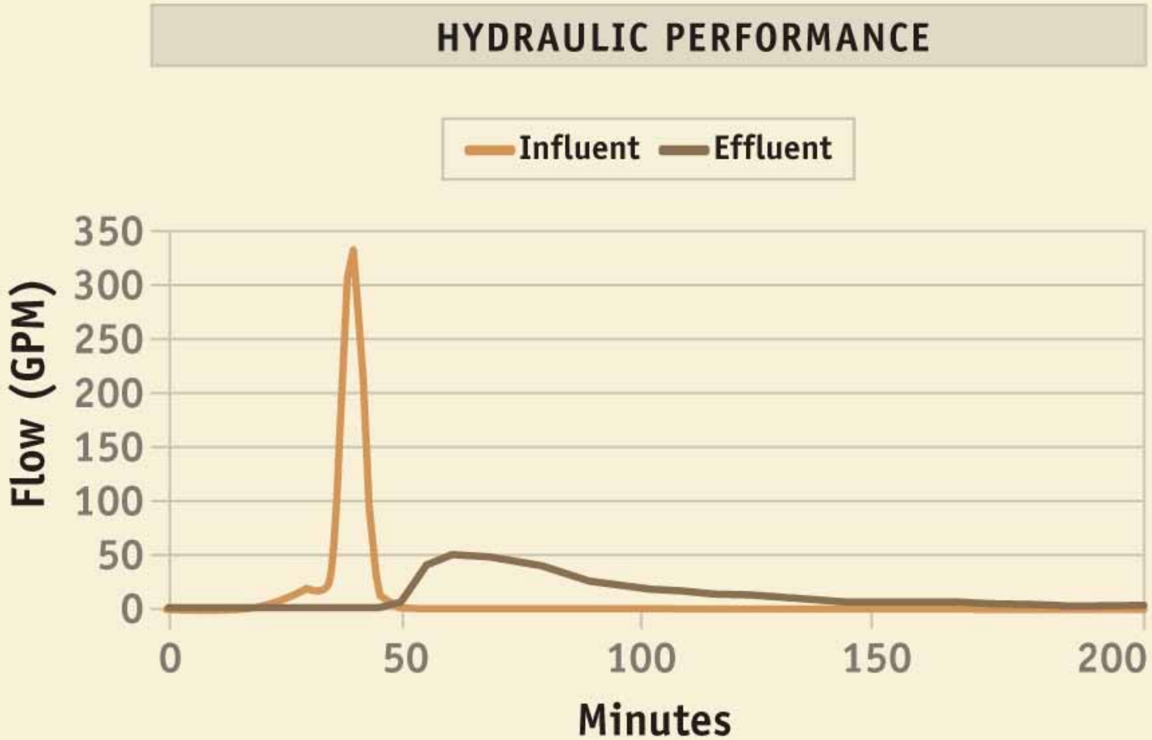


Bioretention System Hydraulic Performance



	Winter	Summer	Annual Average
Average Peak Flow Reduction	NA	NA	82%
Average Lag Time (minutes)	NA	NA	92

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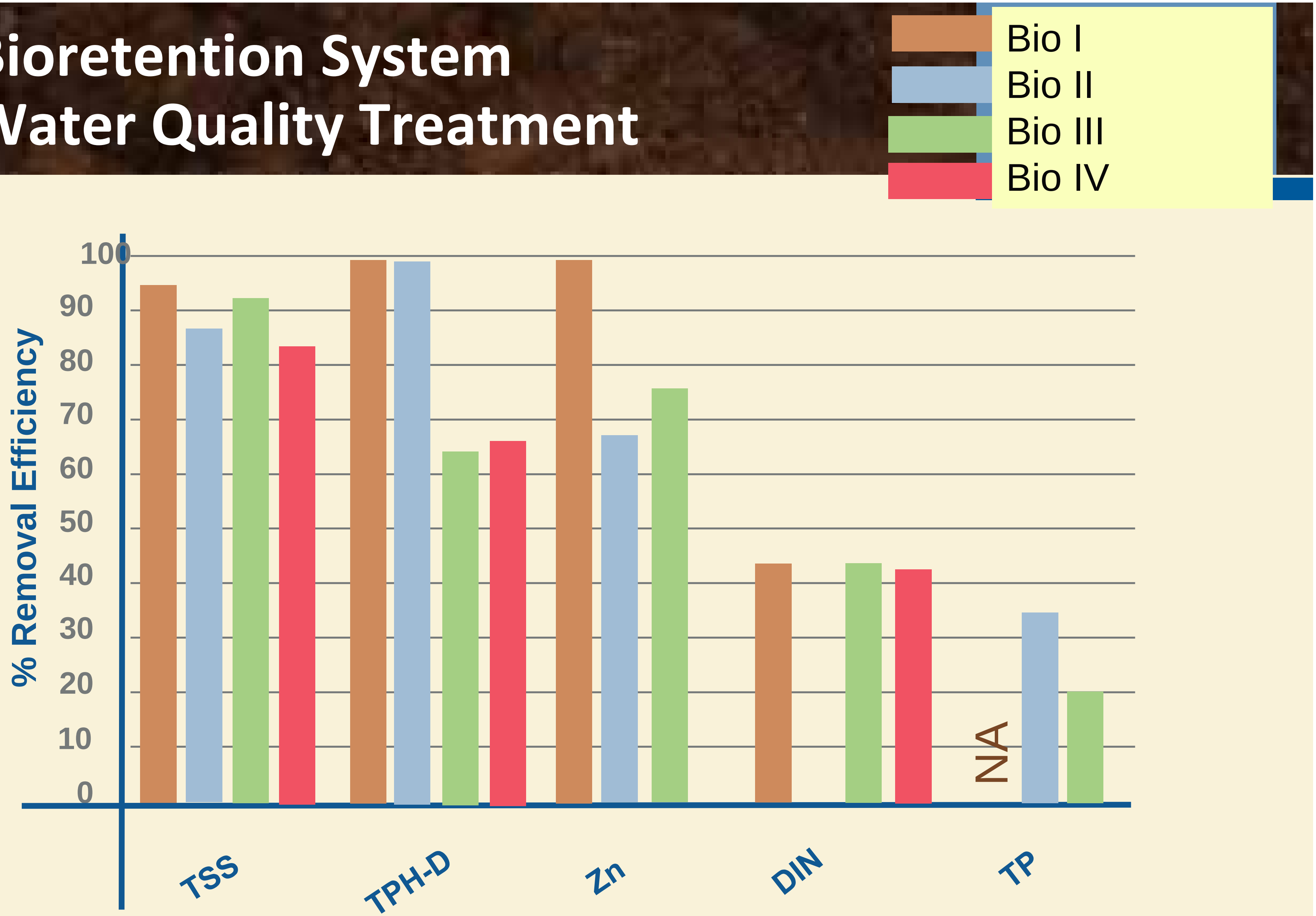
WATER QUANTITY CONTROL

Systems	Winter	Summer	Average
Bioretention 1			
Average Peak Flow Reduction	77%	74%	75%
Average Lag Time (minutes)	408	108	266
Bioretention 2			
Average Peak Flow Reduction	74%	85%	79%
Average Lag Time (minutes)	346	265	309
Bioretention 3			
Average Peak Flow Reduction	84%	85%	84%
Average Lag Time (minutes)	215	217	216
Bioretention 4			
Average Peak Flow Reduction	94%	95%	95%
Average Lag Time (minutes)	52	67	61

Bioretention System
Water Quality Treatment



Tree Filter System
Water Quality Treatment

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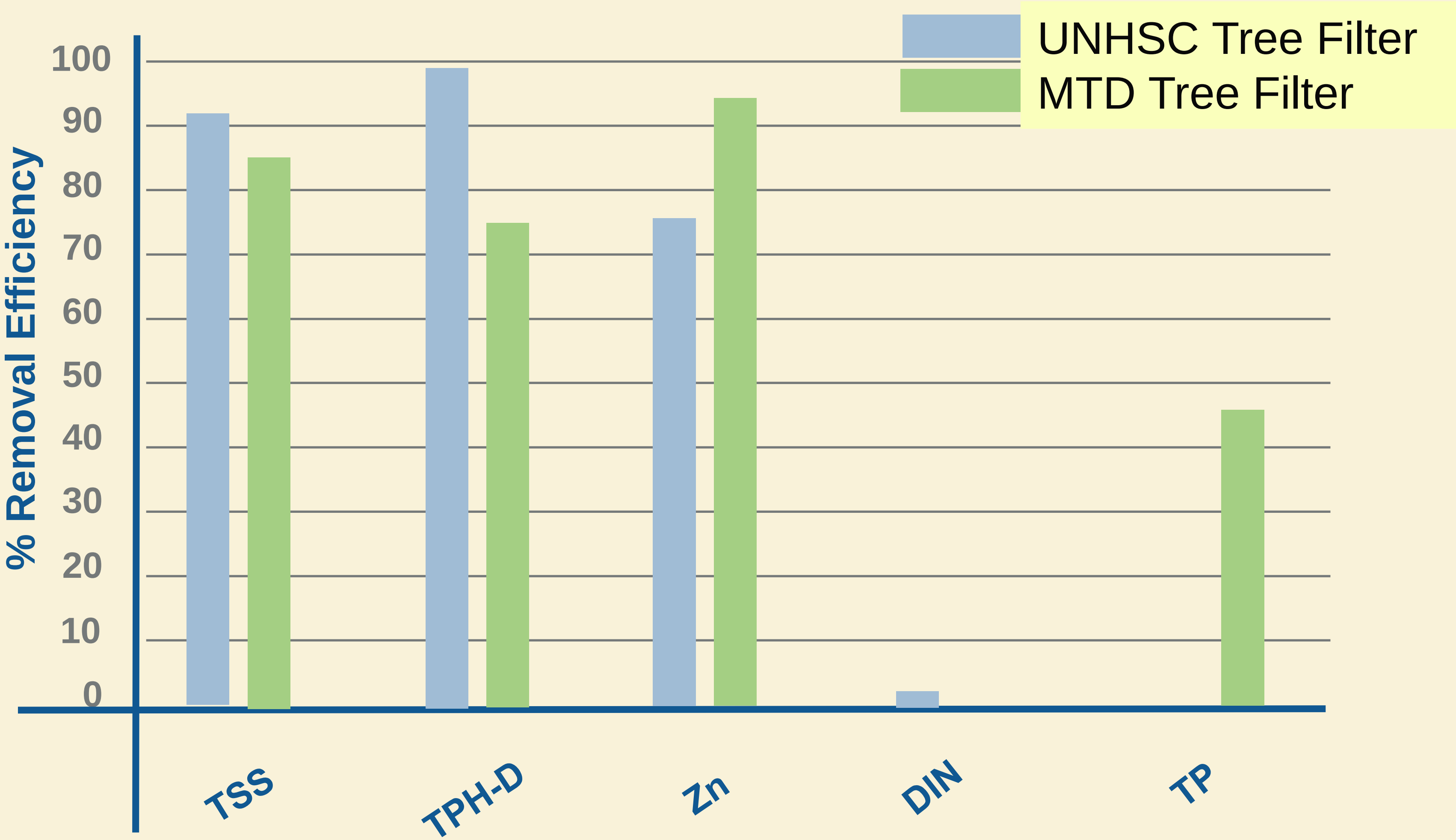
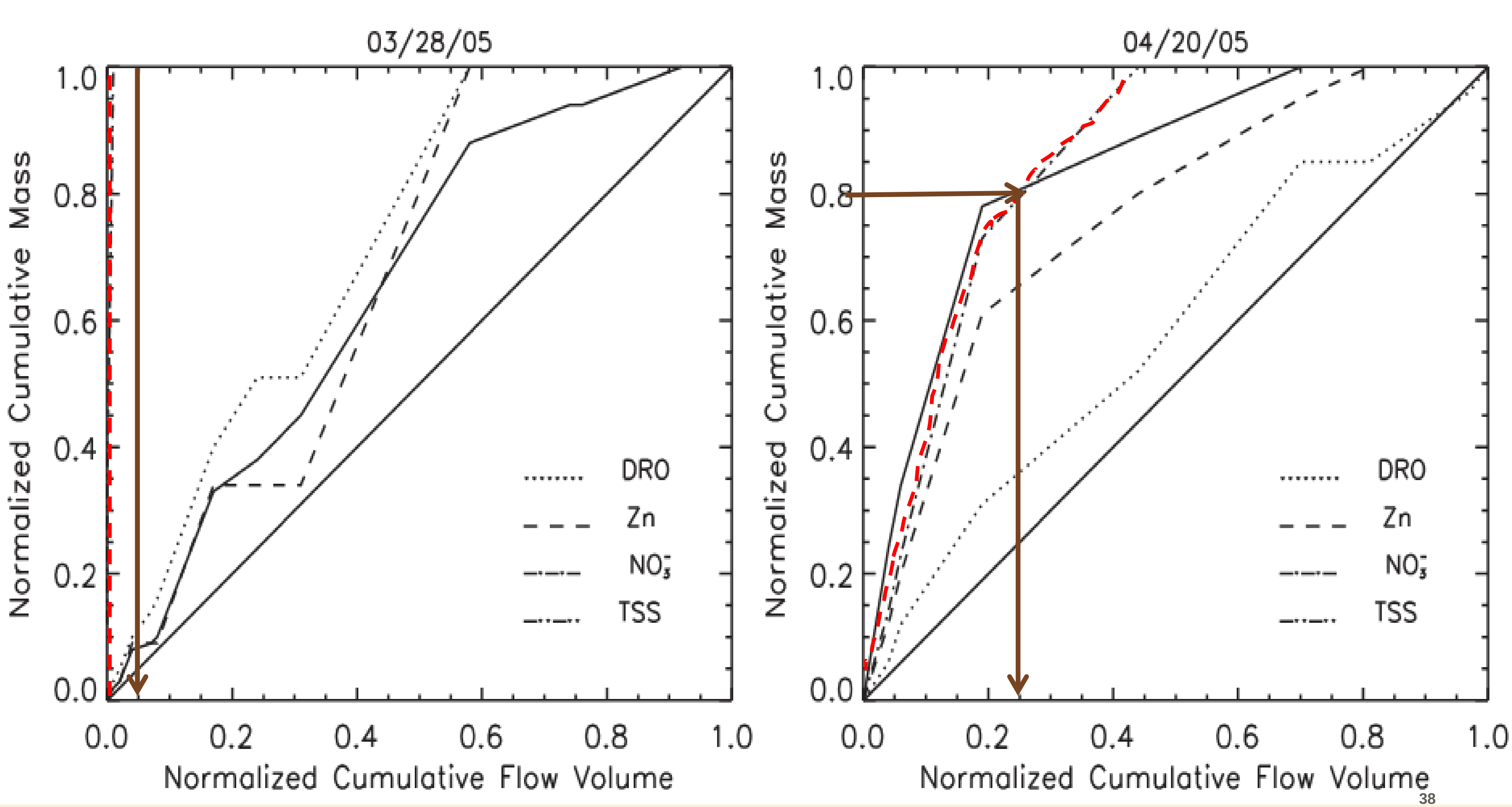
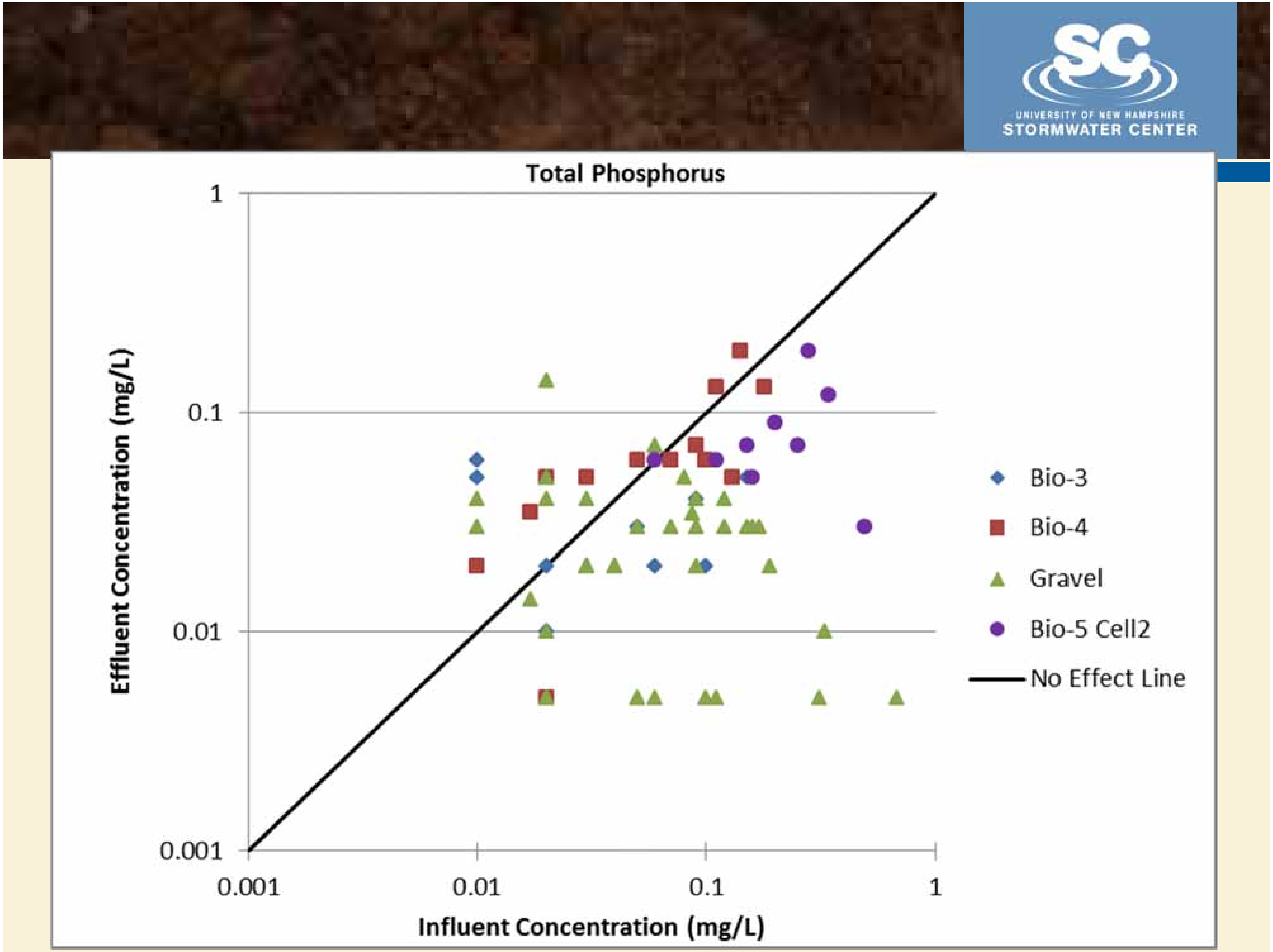


Nitrogen is first flush weighted





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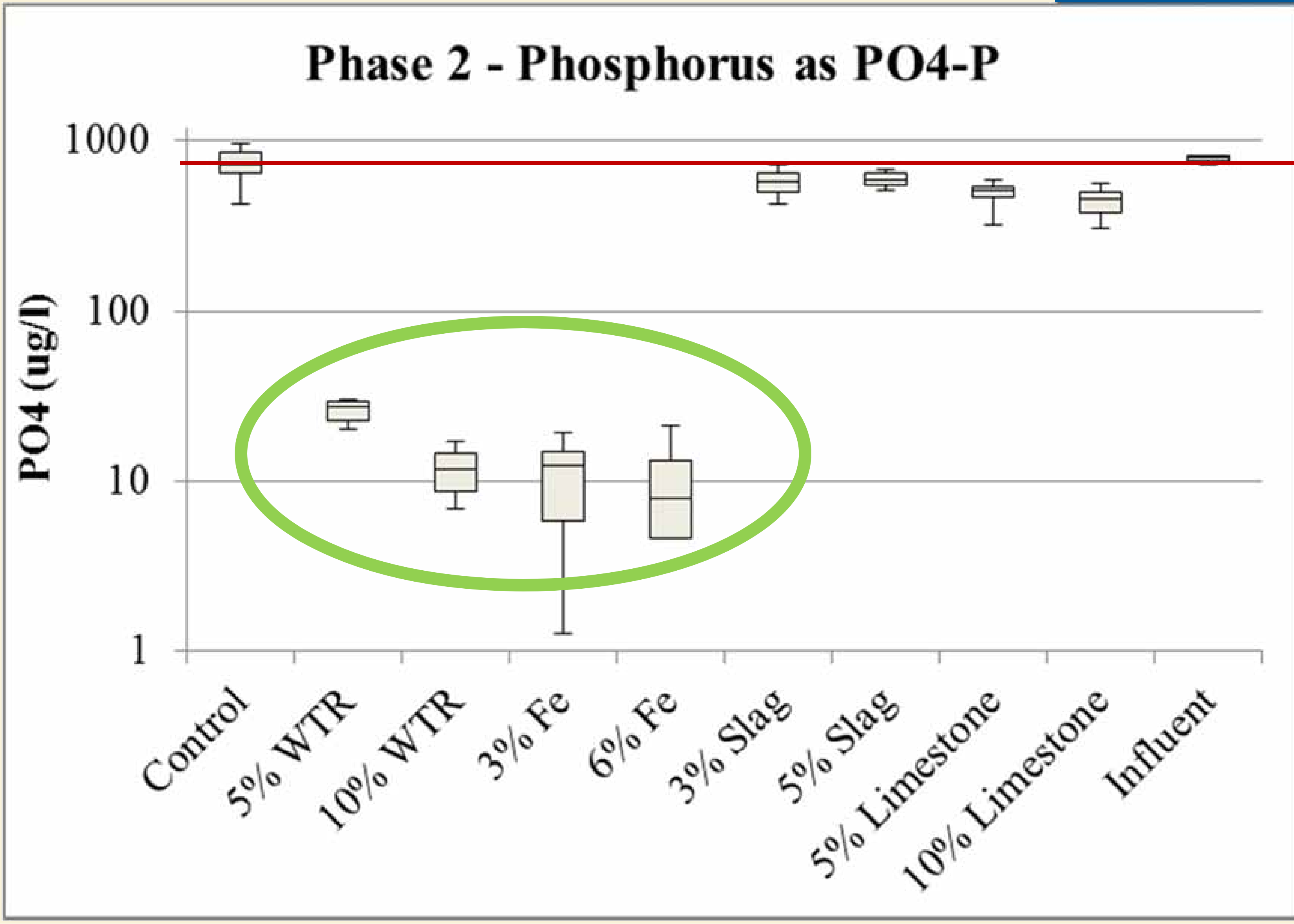
Total Phosphorus
Effluent Concentration (mg/L)
Influent Concentration (mg/L)
1
0.1
0.01
0.001
0.001
0.01
0.1
1
Bio-3
Bio-4
Gravel
Bio-5 Cell2
No Effect Line

Phosphorus Results



Breakthrough

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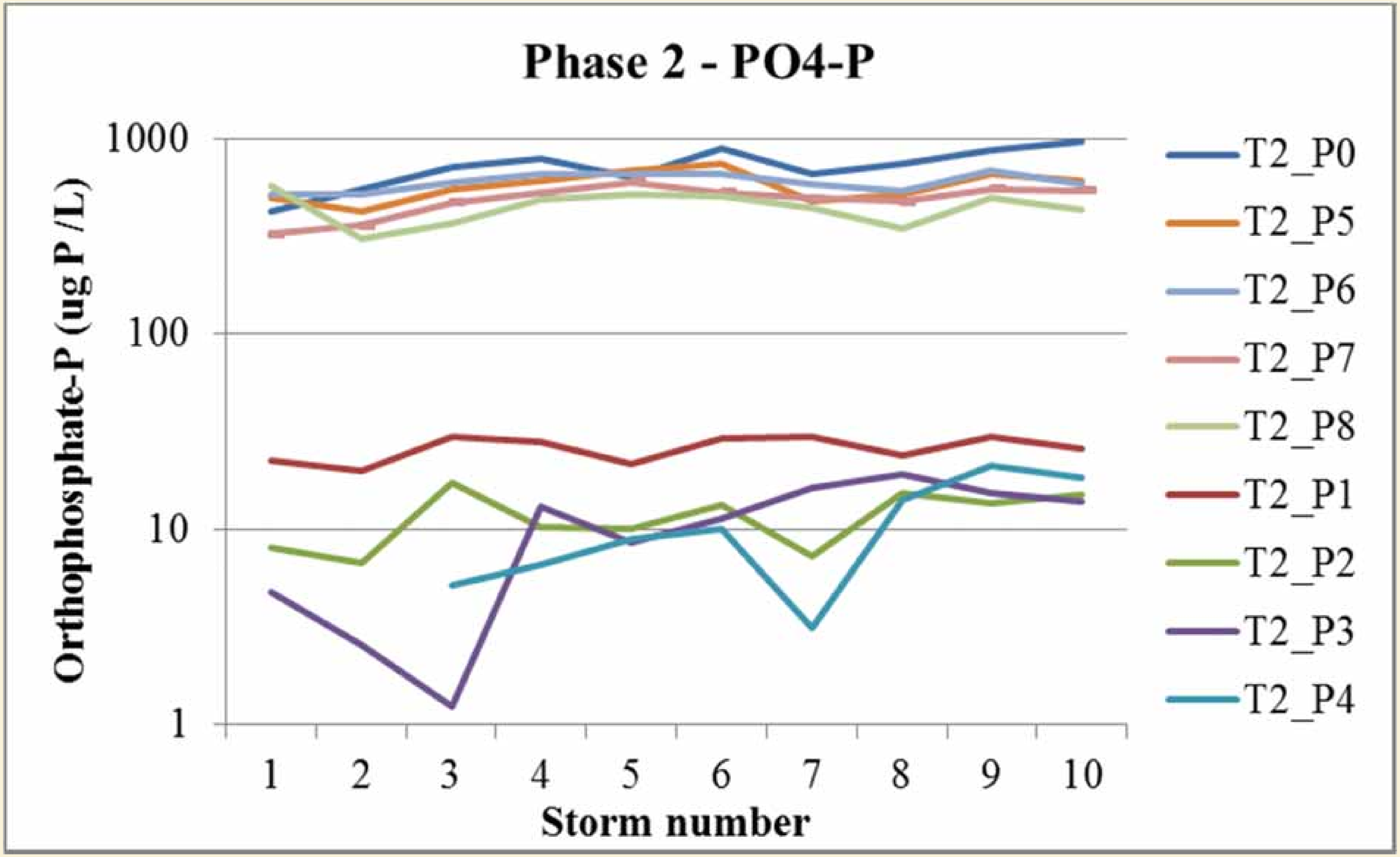
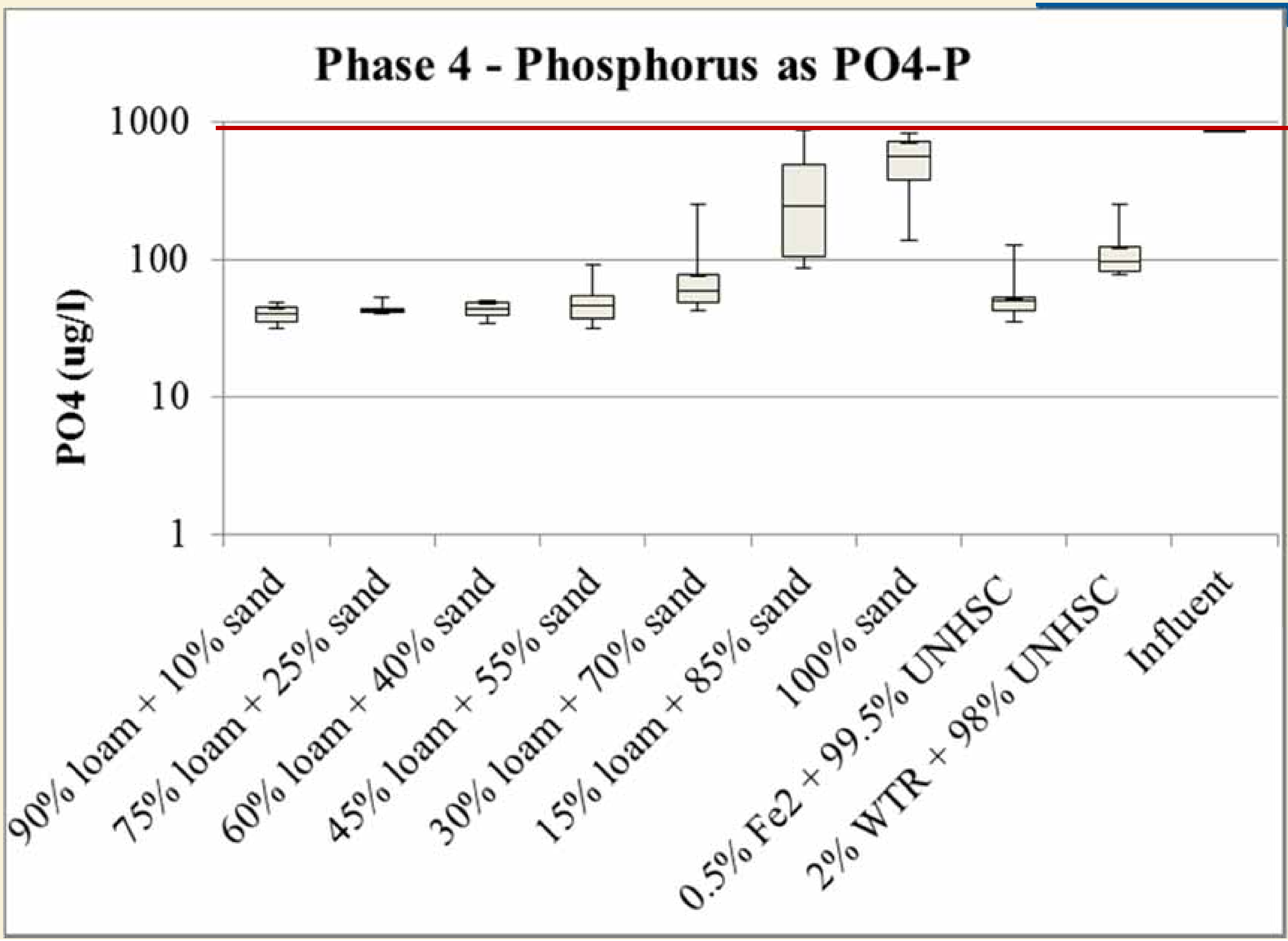


Optimization



Bioretention System Report Card

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CATEGORY	UOP	TARGET	GRADE
Hydrologic	Flow alteration	Divert flow	✓
	Volume reduction		✓
Physical	Sedimentation	Sediment	✓
	Enhanced sedimentation	Sediment	
	Filtration	Sediment	✓
Biological	Microbial	Nitrogen	✓-
	Vegetative	Nitrogen/Phosphorus	✓
Chemical	Sorption	Phosphorus	✓-

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Subsurface Gravel Wetland

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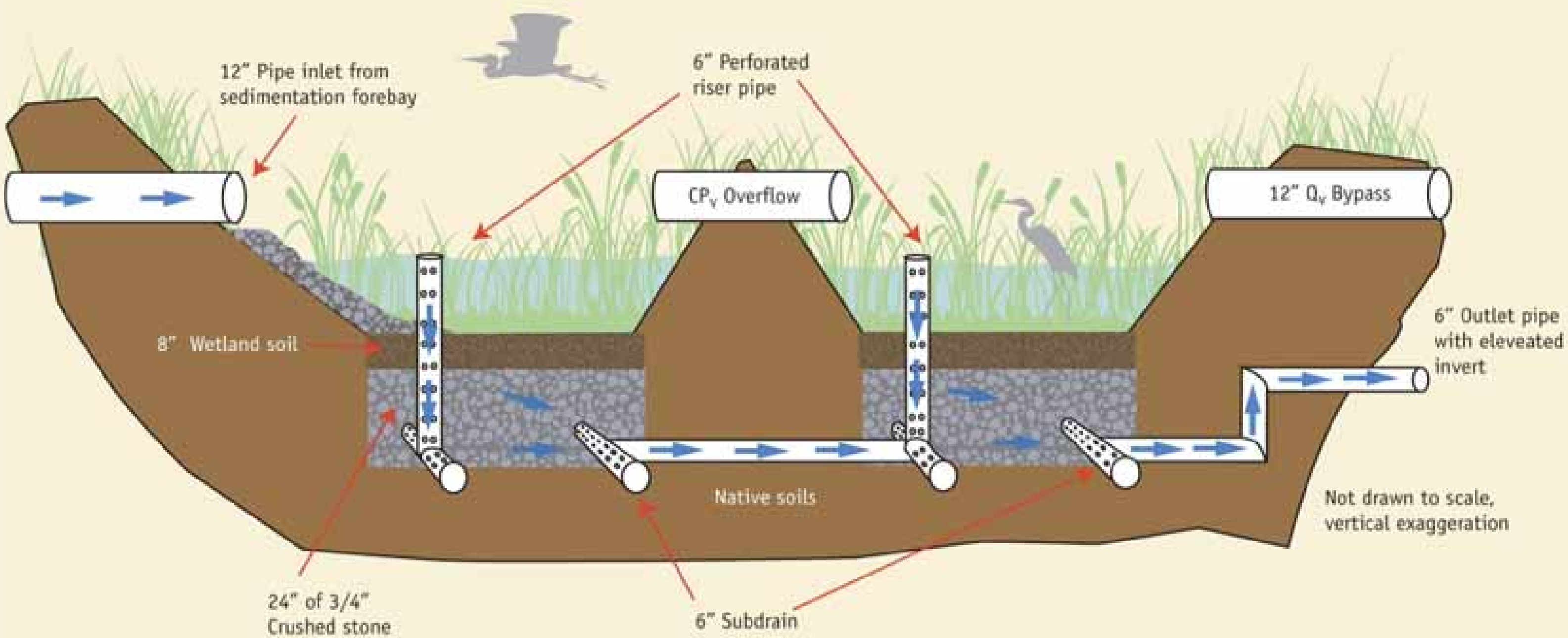
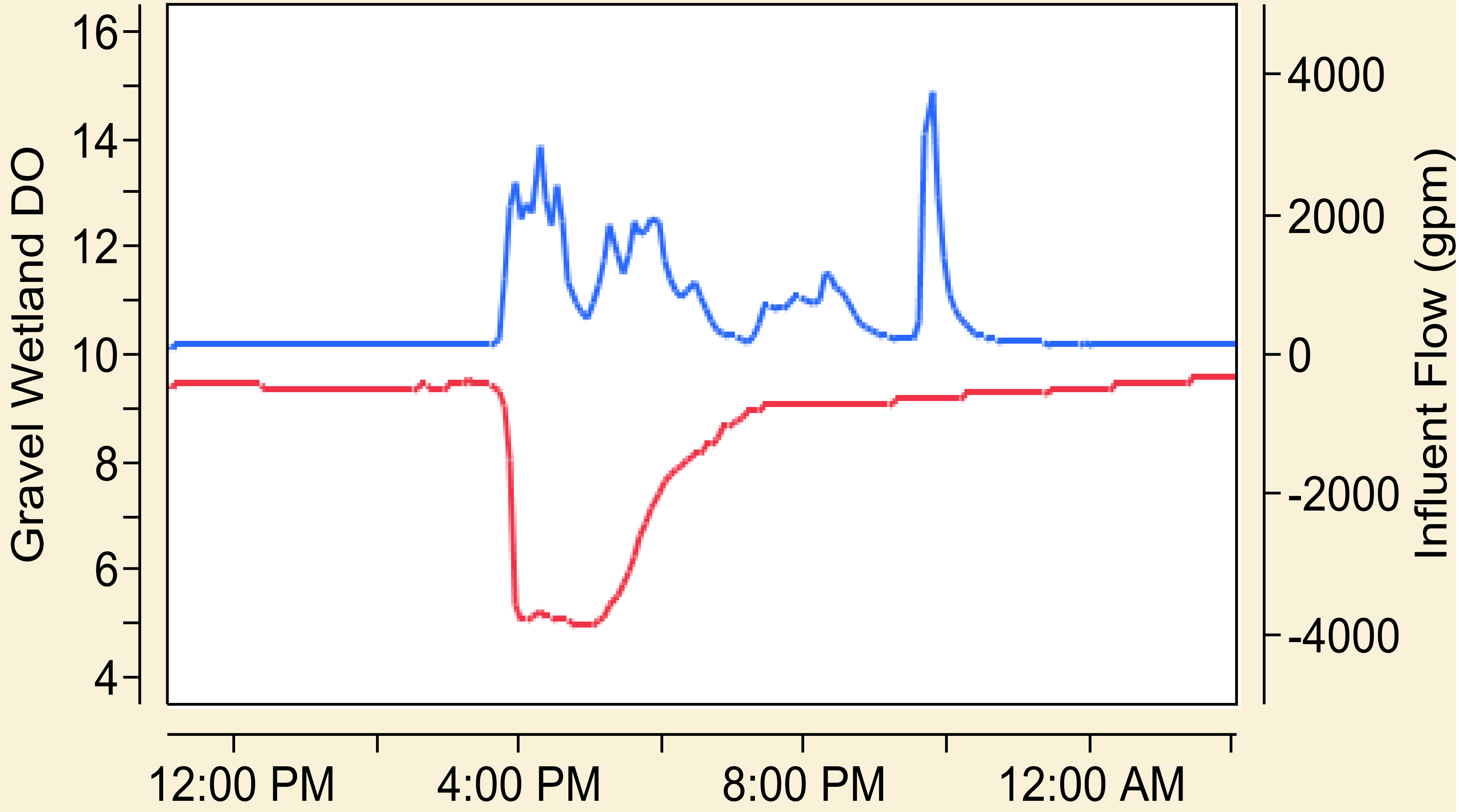
Subsurface Gravel Wetland Components



Dissolved Oxygen in Gravel Wetland Effluent



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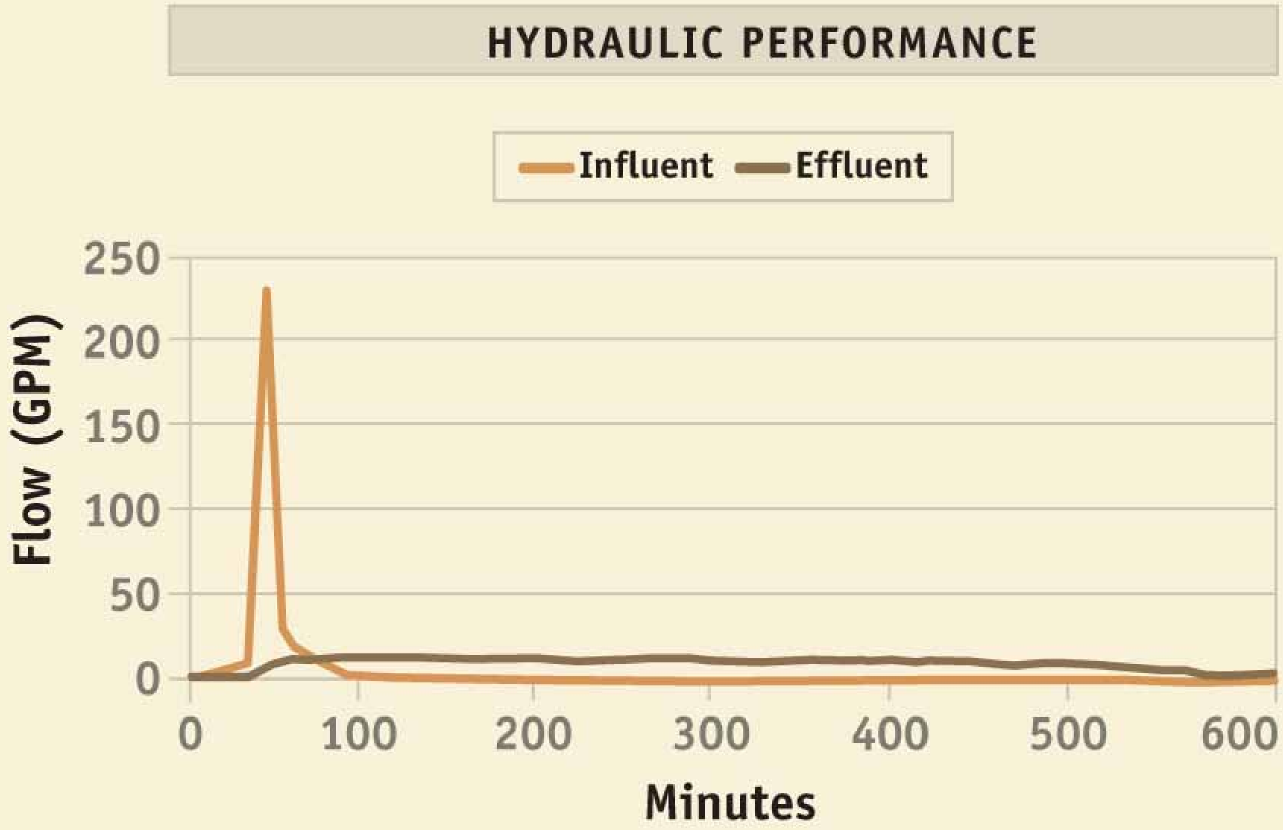
Subsurface Gravel Wetland Hydraulic Performance



	Winter	Summer	Annual Average
Average Peak Flow Reduction	85%	77%	81%
Average Lag Time (minutes)	318	313	315

Subsurface Gravel Wetland MedianRemoval Efficiencies

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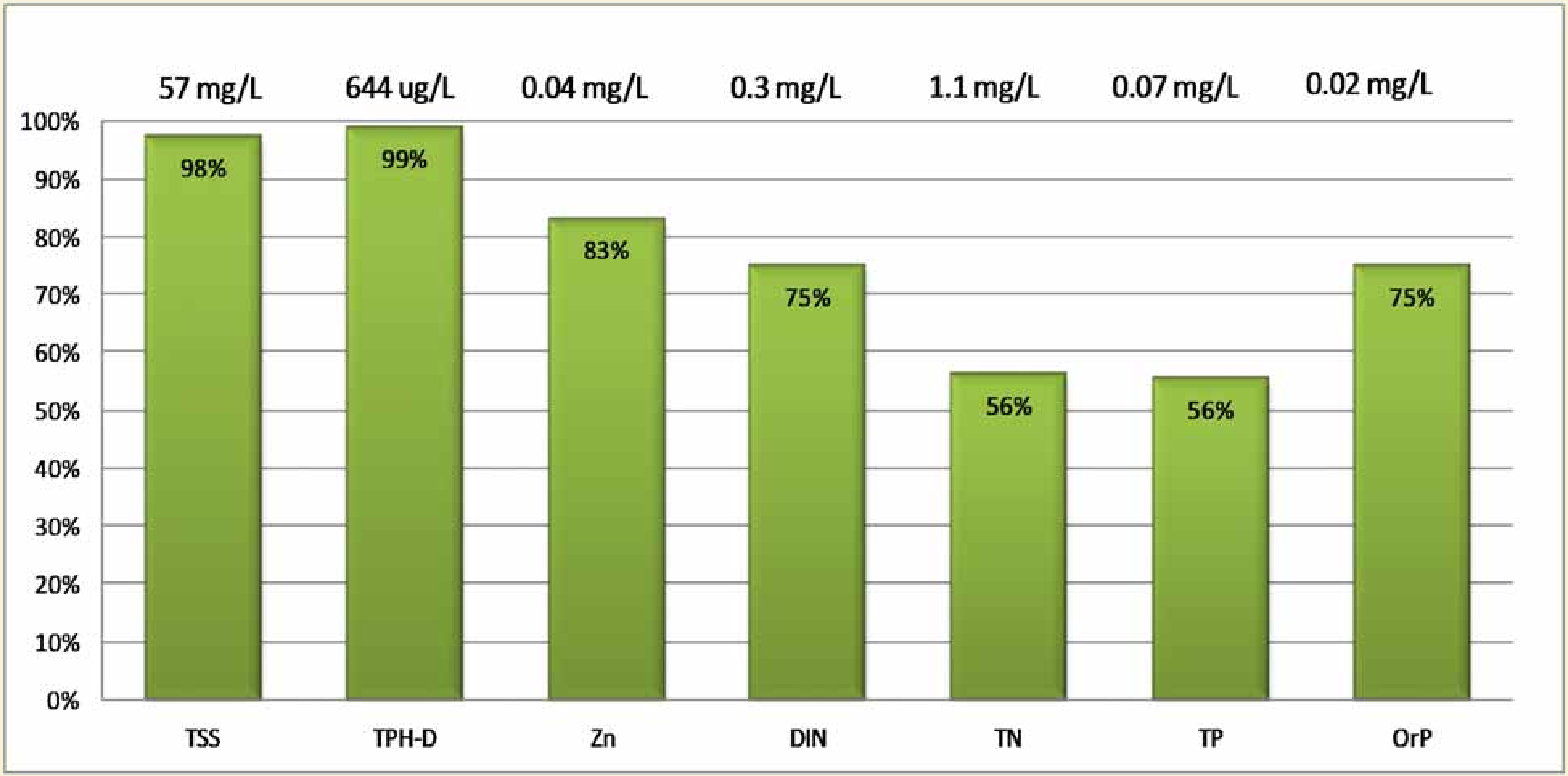
6 years of data with Influent EMC medians



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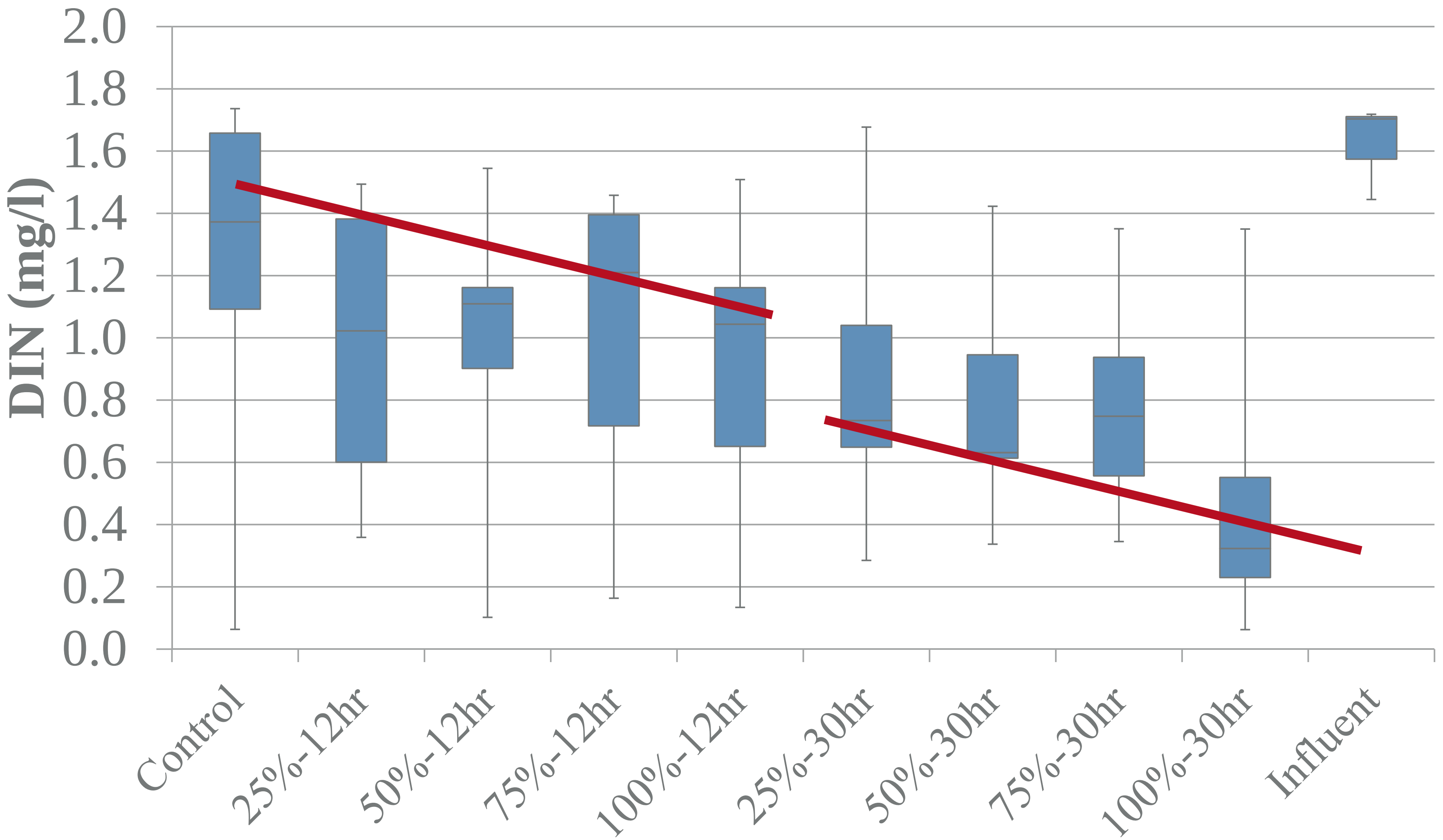
Nitrogen Results



Other Questions

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What is the max design ponding depth?

A: It depends on chosen plant communities and the possibility of driving water vertically through the wetland soil. Preferably = 18 in.

Is the WQV storage in the system static or dynamically sized?

A: Static. Volume of storage above-ground is equal to the WQV. Draindown is controlled by the restrictive outlet hydraulics

Other Questions

How important is the 2-cell treatment approach?

A: The primary benefit is the built-in redundancy should one of the cells need repair or maintenance.

Is there a specific reason for the 15’ flow path?

A: Some of our tests with a horizontal flow gravel sluice verified this sizing based on performance.

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Gravel Wetland Report Card

category	uop	target	"grade"
hydrologic	flow alteration	divert flow	✓
	volume reduction		
physical	sedimentation	sediment	✓
	enhanced sedimentation	sediment	
	filtration	sediment	✓
biological	microbial	nitrogen	✓+
	vegetative	nitrogen phosphorus	✓+
chemical	sorption	phosphorus	✓

Pervious Pavements

Porous Pavements Design

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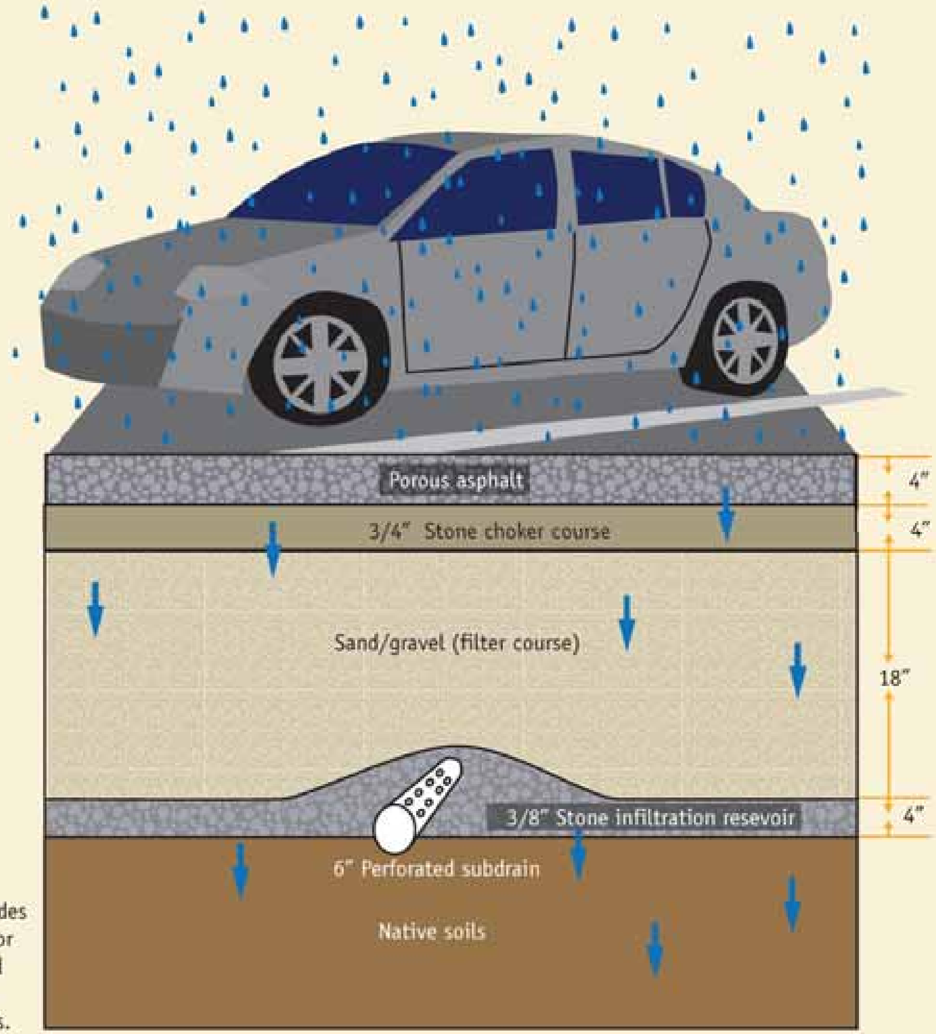

Please note:
This design includes subbase design for cold climates and drainage for low permeability soils.

Hydraulic Performance of Porous Pavements

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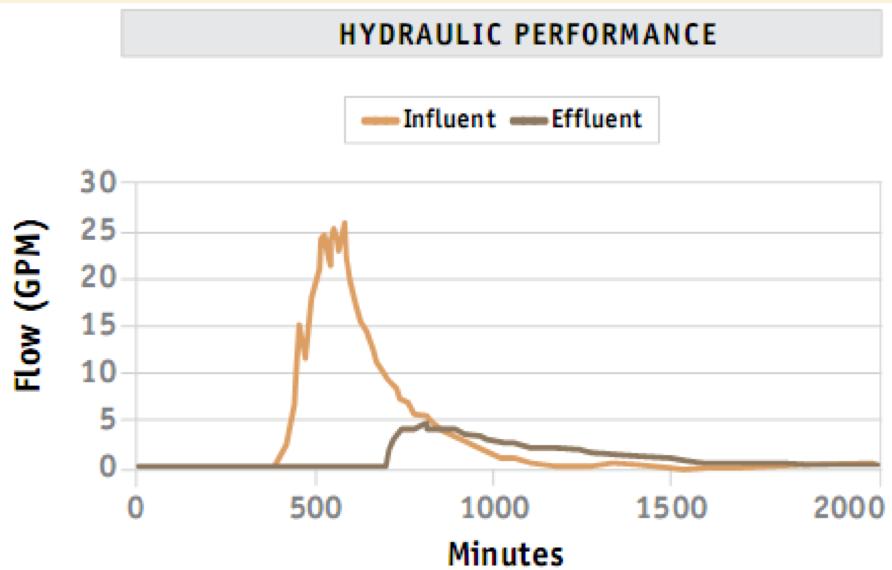
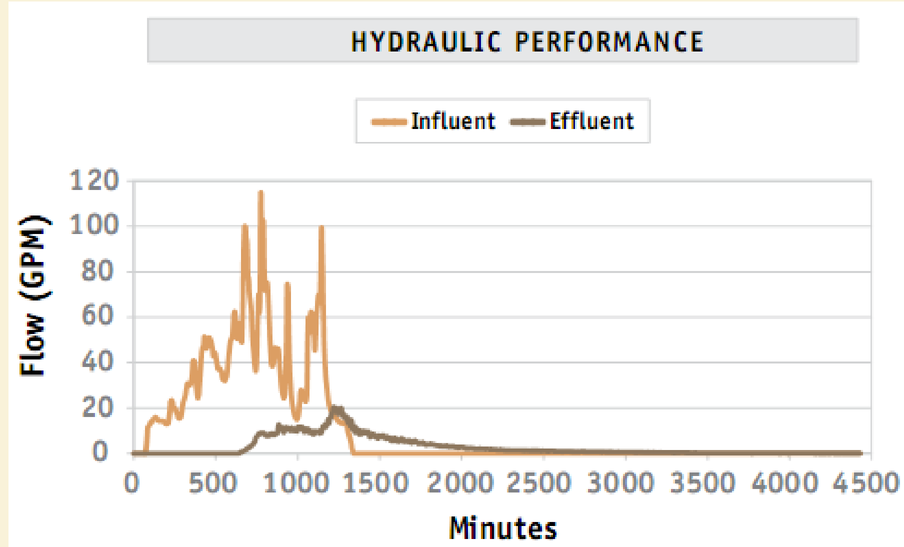
Porous Asphalt (HSG-C)



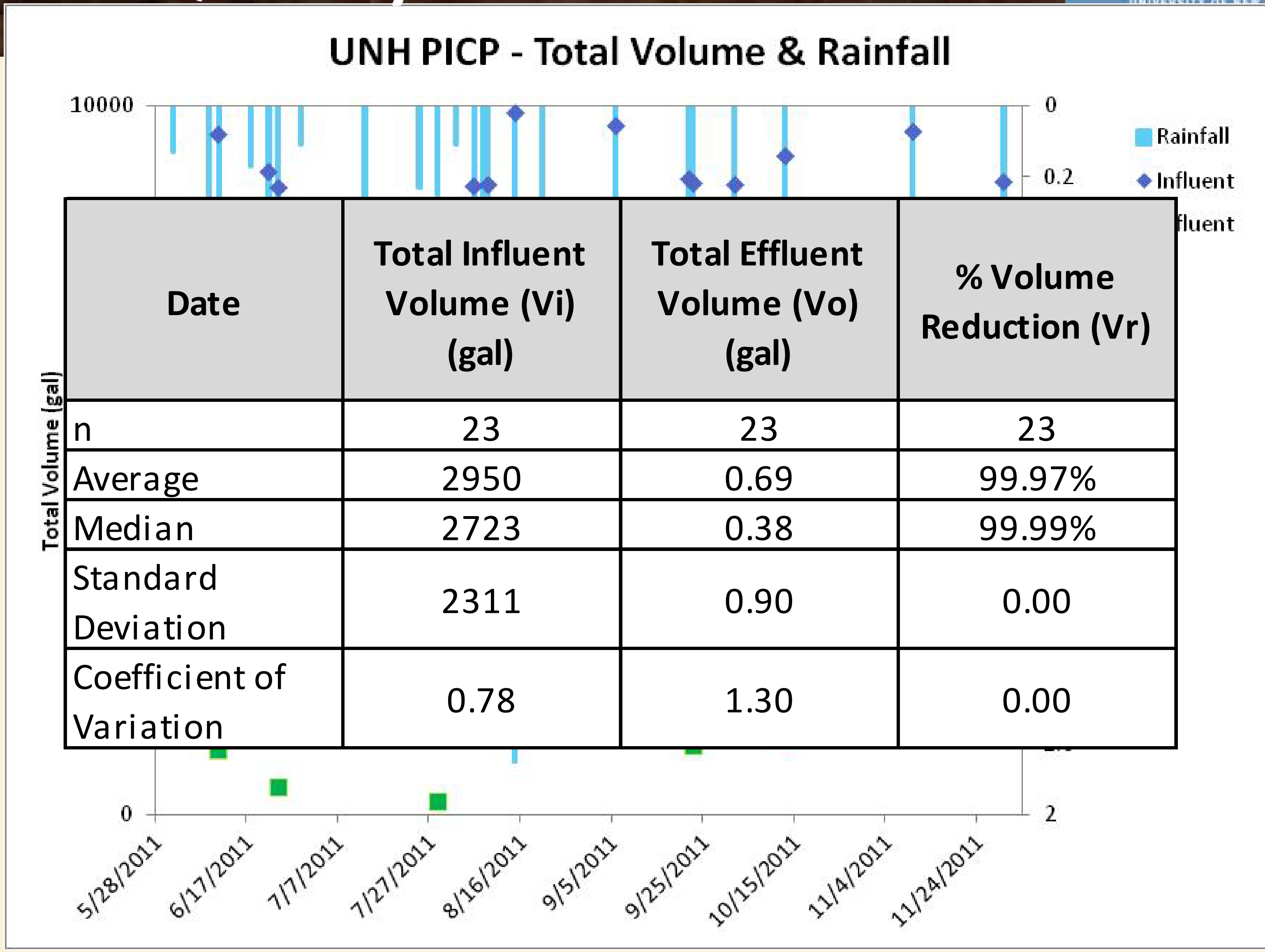
	Winter	Summer	Annual Average
Average Peak Flow Reduction	76%	86%	82%
Average Lag Time (minutes)	1,163	1,375	1,275

Pervious Concrete (HSG-B)



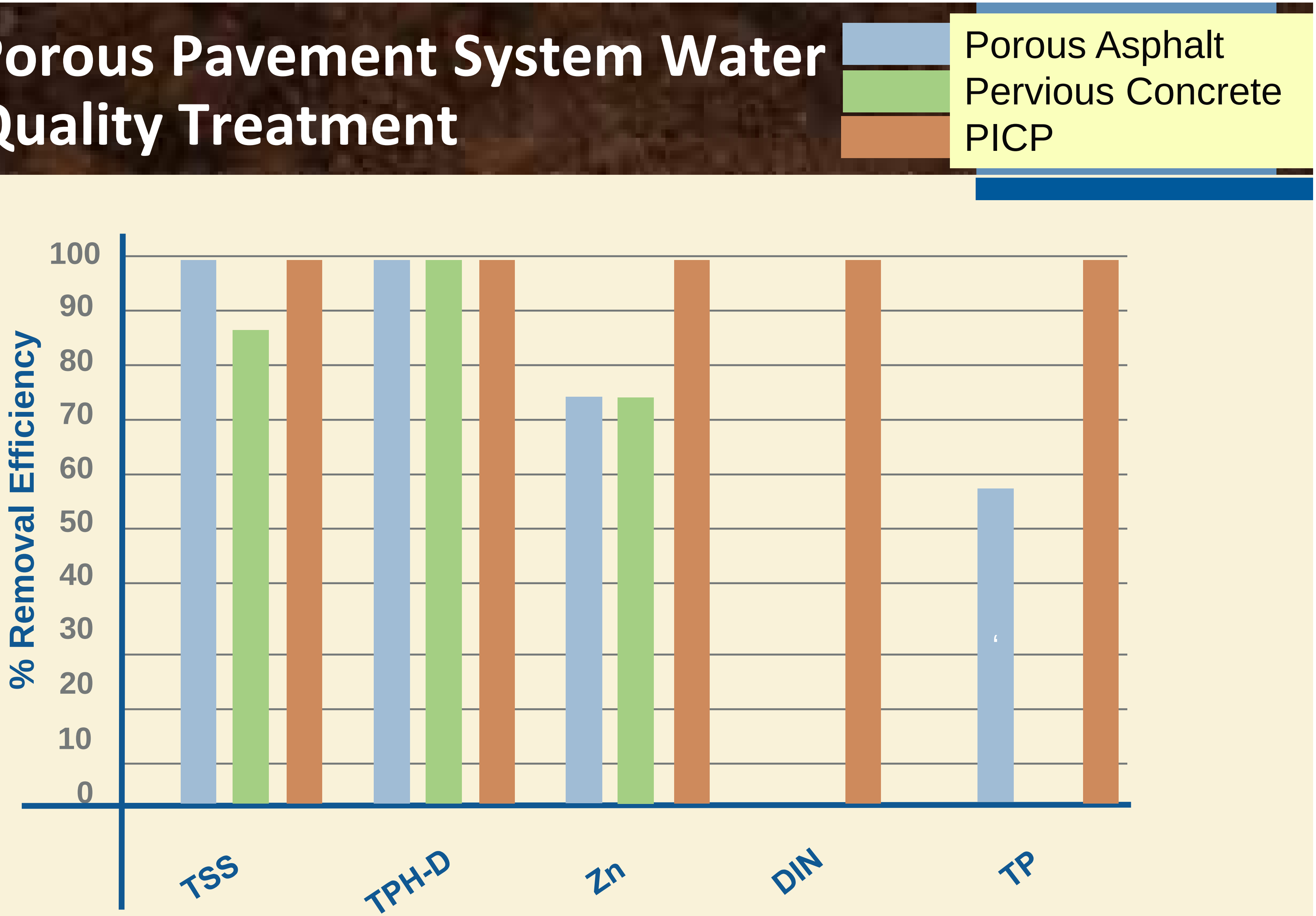
	Winter	Summer	Annual Average
Average Peak Flow Reduction	88%	97%	93%
Average Lag Time (minutes)	848	1,365	1,144
Average Volume Reduction	91%	98%	95%

Water Quantity

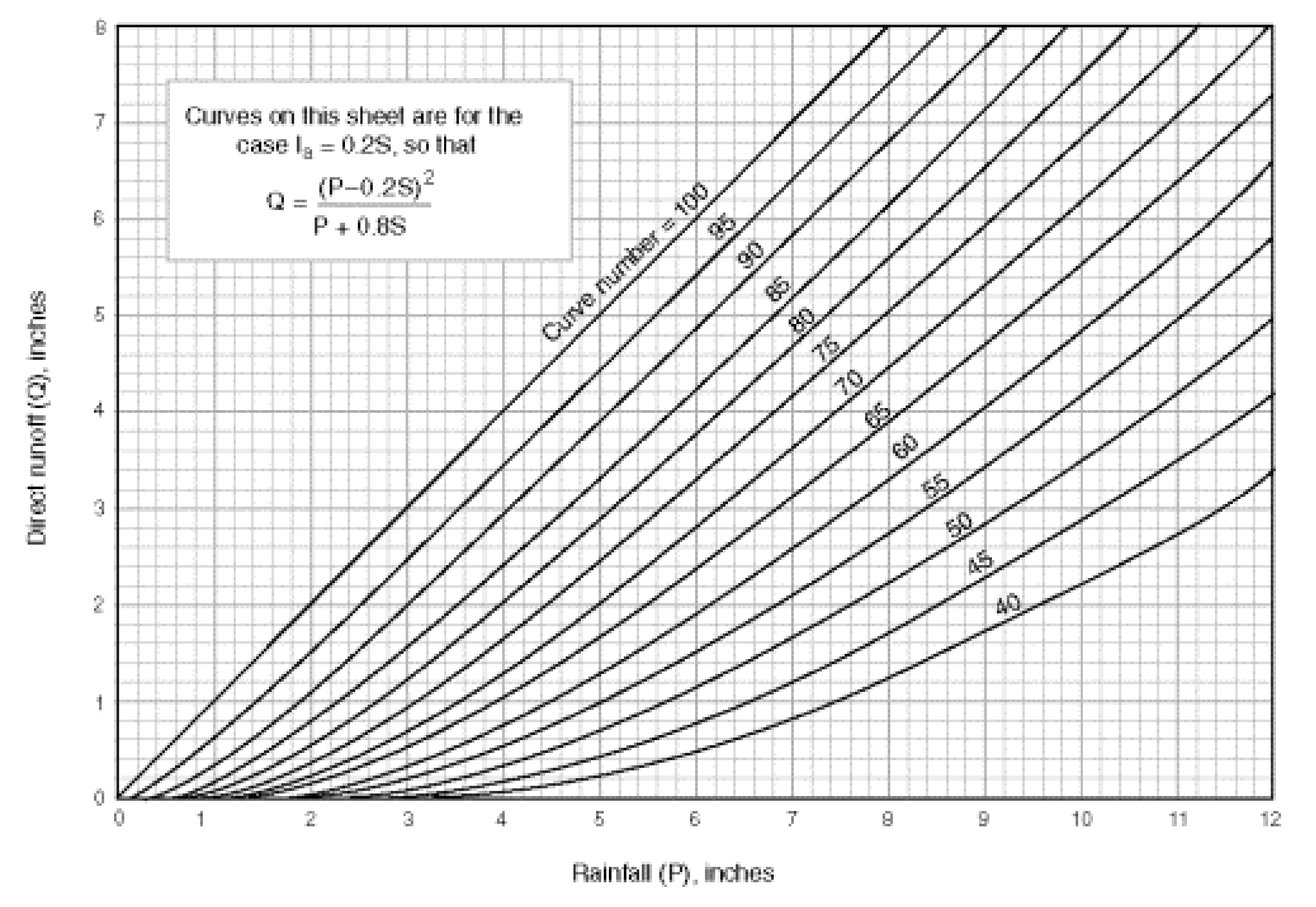


Date	Total Influent Volume (Vi) (gal)	Total Effluent Volume (Vo) (gal)	% Volume Reduction (Vr)
n	23	23	23
Average	2950	0.69	99.97%
Median	2723	0.38	99.99%
Standard Deviation	2311	0.90	0.00
Coefficient of Variation	0.78	1.30	0.00

Porous Pavement System Water Quality Treatment



Curve Number



Methods of Teasing CN from the Data

1. Method 1-- Depth of Runoff: Measure P and Q, invert basic SCS equation

2. Method 2-- Lag Method: Measure P and outflow hydrograph (q), measure lag, estimate CN from lag equations

3. Method 3– Graphical Peak Discharge: Measure Q and q_p, estimate CN from peak discharge equations

Results

	CN Method 1	CN Method 2 Method A	CN Method 2 Method B	CN Method 2 Method C	CN Method 3
Average	74	11	6	6	51
Median	75	8	2	3	13

Natural state for Hinckley-Charlton soil (HSG – B/C)
= 60 - 72

Temperature

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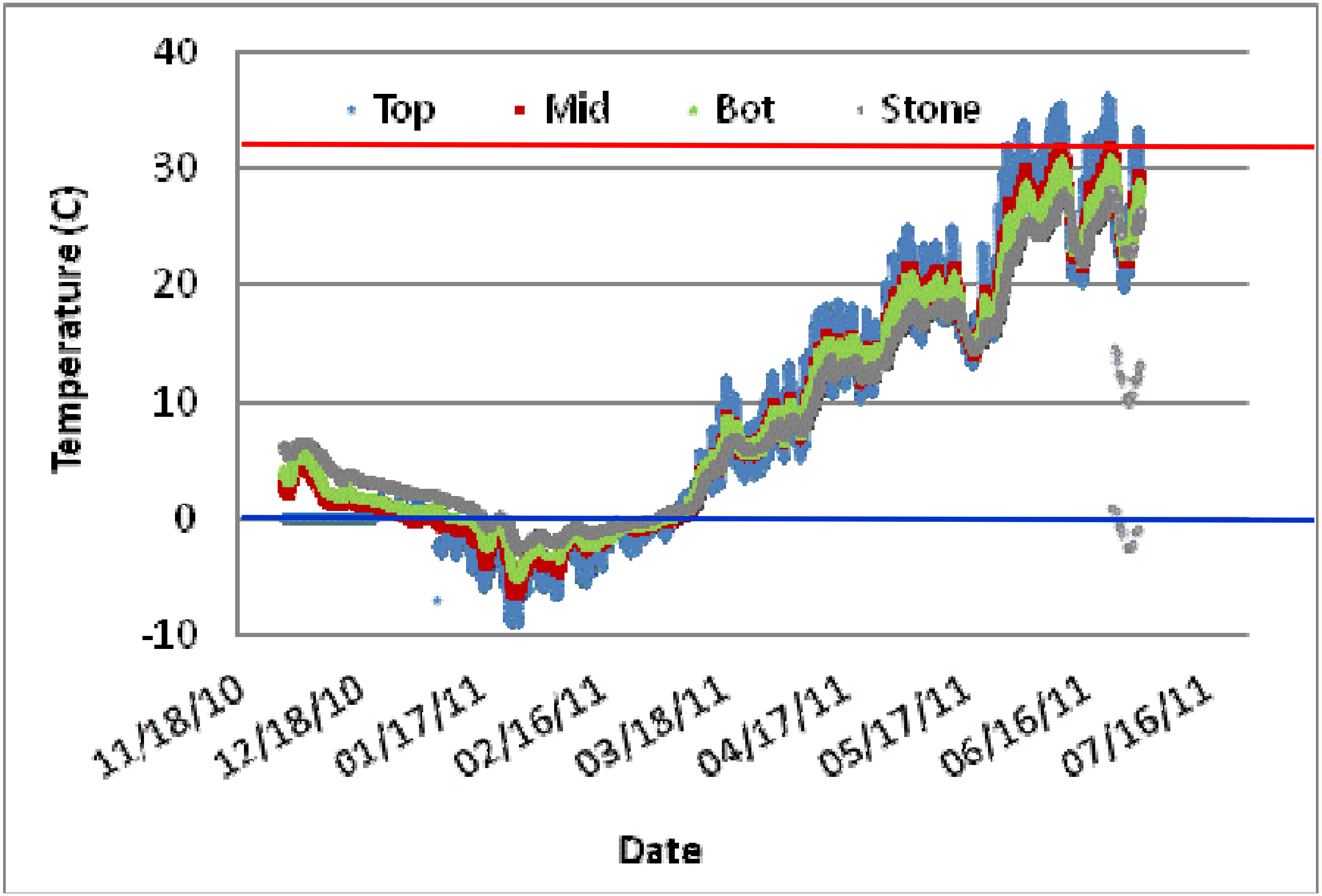

Summer Temperatures

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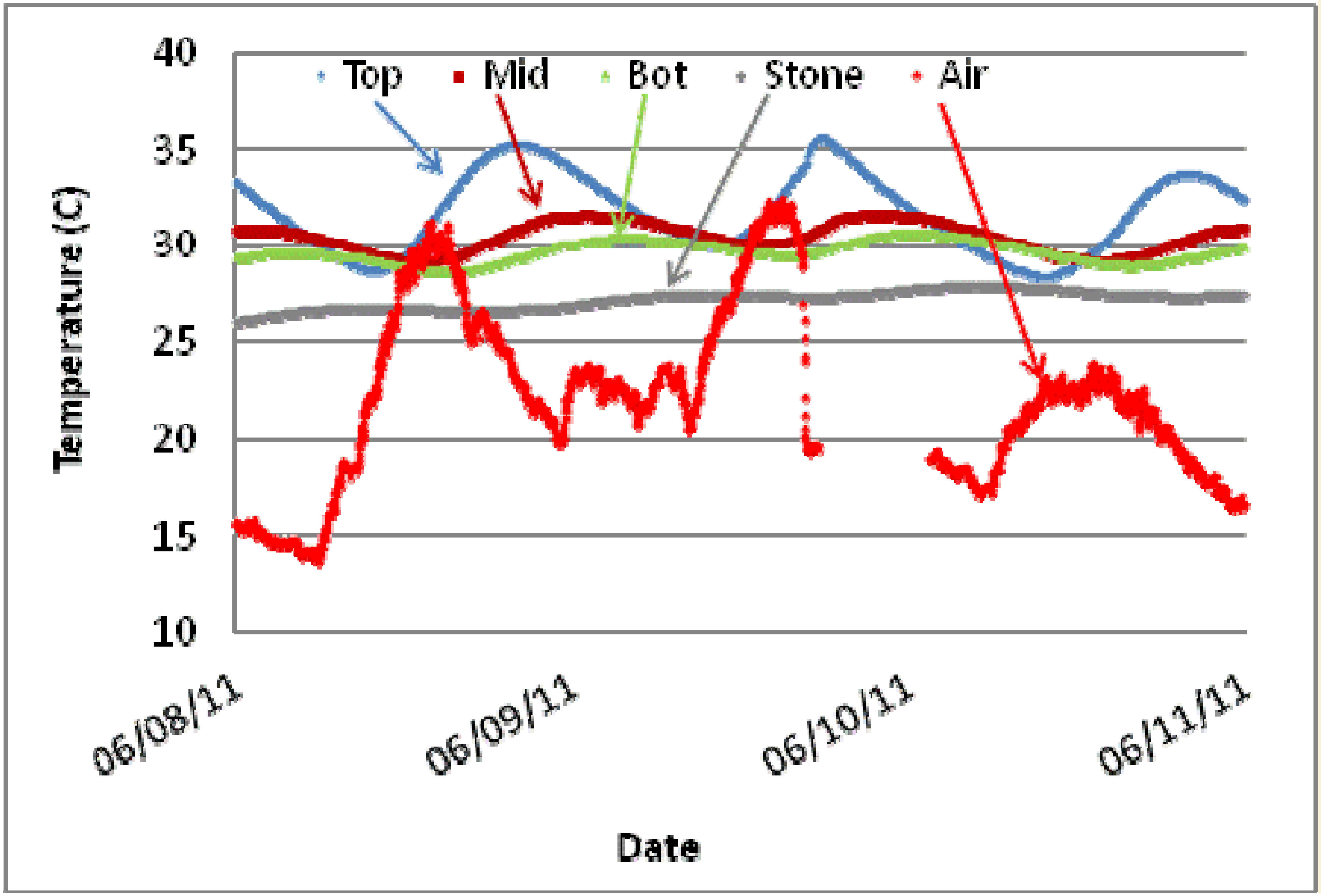

Side by Side….

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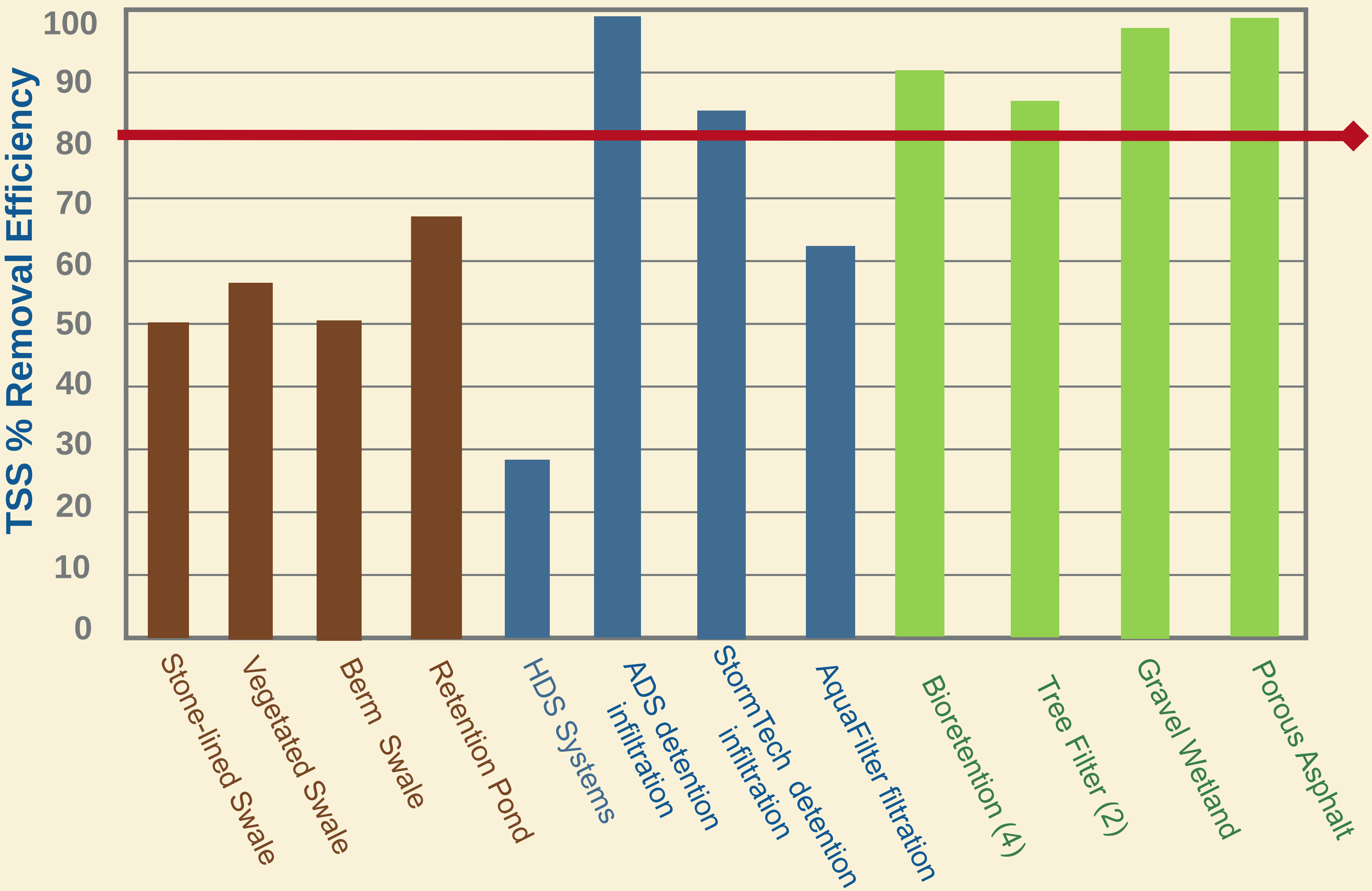
How do they compare?

TSS Removal Efficiencies



DIN Removal Efficiencies

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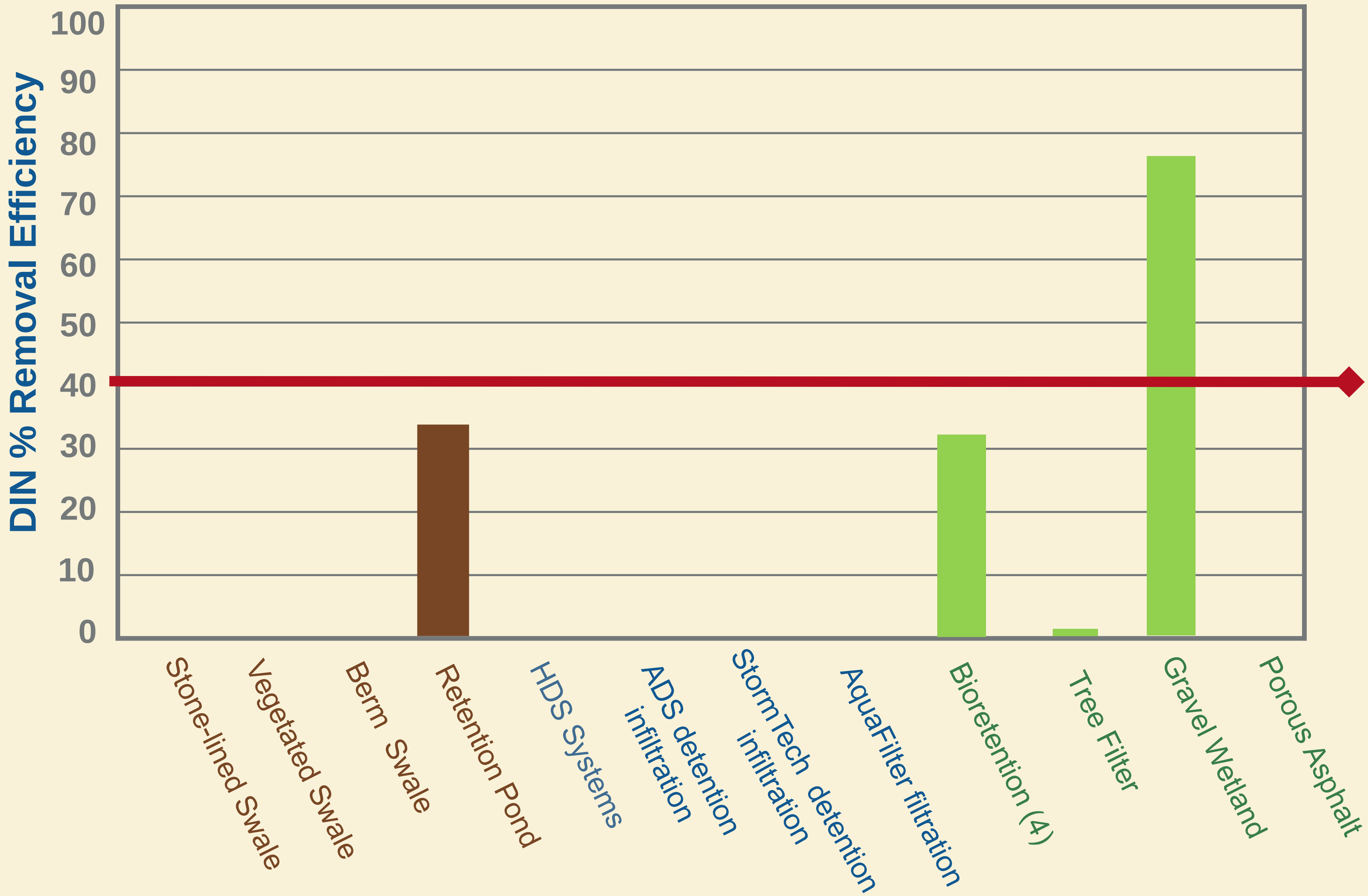
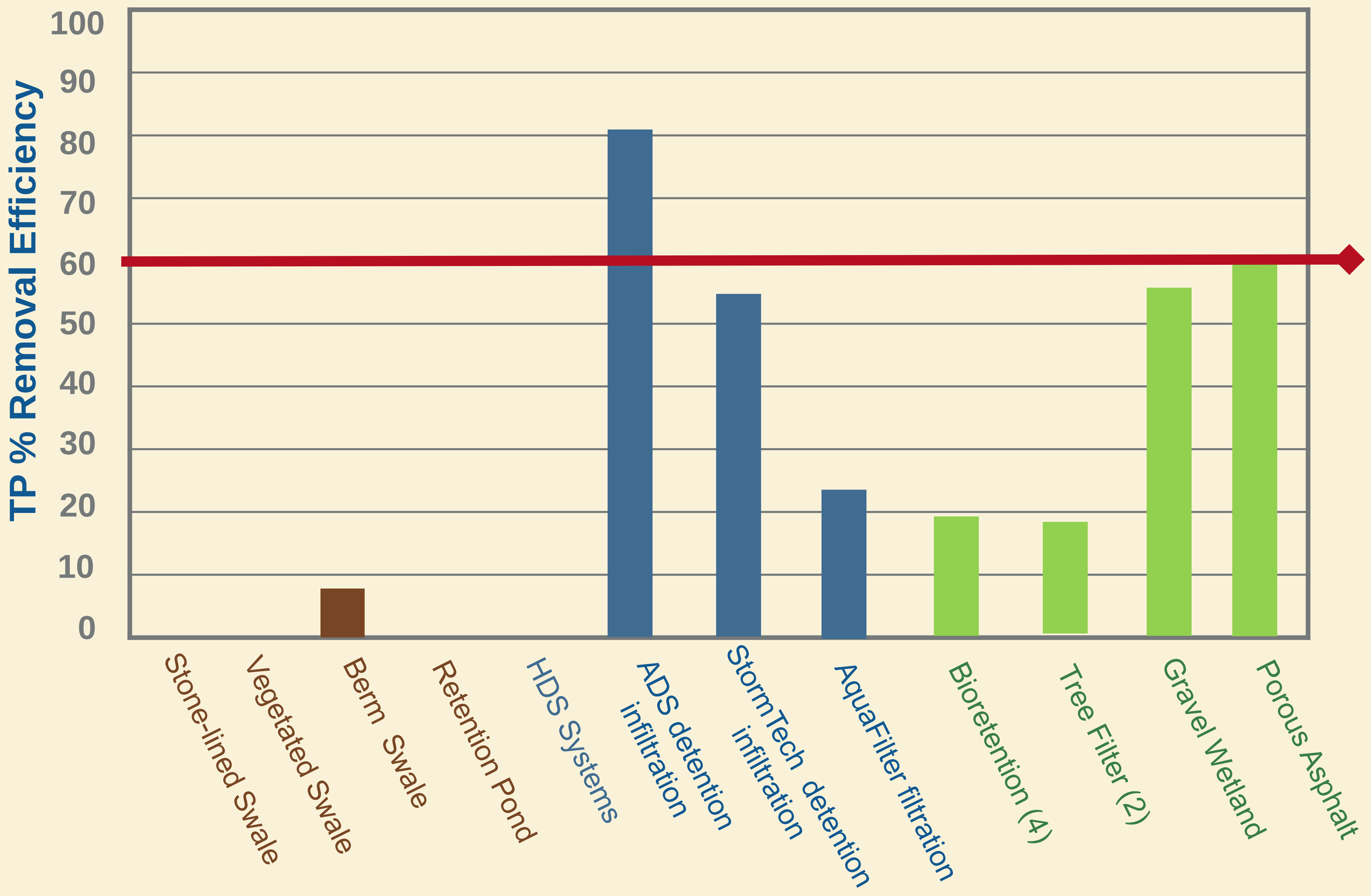


TP Removal Efficiencies



Site Level Case Studies

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Boulder Hills, Pelham, NH

- 2009 Installation of 900’ of first PA private residential road in Northeast
- LID subdivision 55+ Active Adult Community
- Large sand deposit
- Cost 25% greater per ton installed

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Conventional Site Design

LID Design

Boulder Hills

- Built on 9% grade
- Avoided use of 1616’ of curbing, 785’ pipe, 8 catch-basins, 2 detention basins, 2 outlet control structures
- 1.3 acres less of land clearing
- Conventional SWM=$789,500 vs LID SWM=$740,300,
- $49,000 savings (6.2%)

Comparison of Unit Costs

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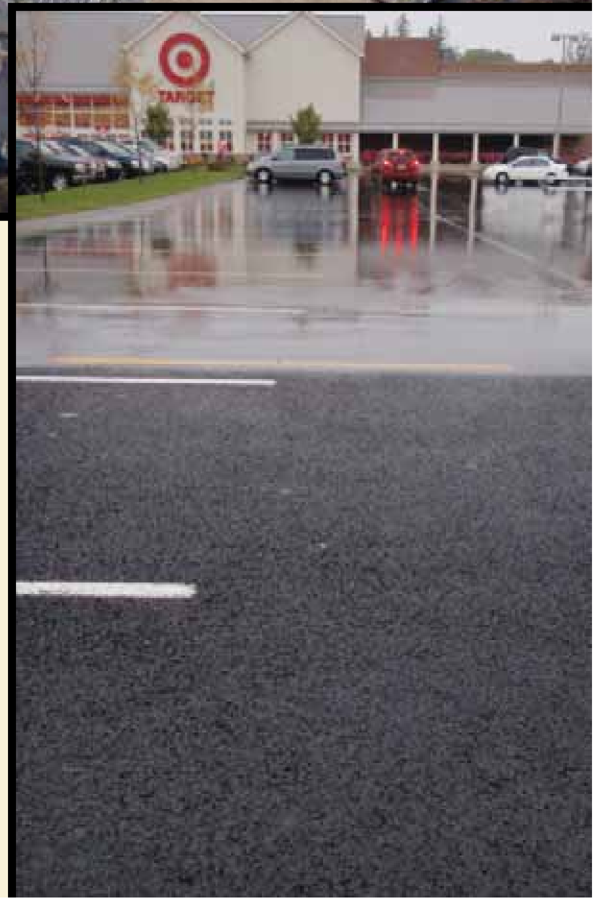
Item	Conventional	LID	Difference
SITE PREPARATION	$23,200.00	$18,000.00	–$5,200.00
TEMP. EROSION CONTROL	$5,800.00	$3,800.00	–$2,000.00
DRAINAGE	$92,400.00	$20,100.00	–$72,300.00
ROADWAY	$82,000.00	$128,000.00	$46,000.00
DRIVEWAYS	$19,700.00	$30,100.00	$10,400.00
CURBING	$6,500.00	$0.00	–$6,500.00
PERM. EROSION CONTROL	$70,000.00	$50,600.00	–$19,400.00
ADDITIONAL ITEMS	$489,700.00	$489,700.00	$0.00
BUILDINGS	$3,600,000.00	$3,600,000.00	$0.00
PROJECT TOTAL	$4,389,300.00	$4,340,300.00	–$49,000.00

6% savings on total cost of SW infrastructure for a ~zero discharge site

Greenland Meadows

- “Gold-Star” Commercial
- Development
- Cost of doing business
- near Impaired Waters/303D
- Saved $900k in SWM on costly piping and advanced SWM proprietary
- Brownfields site, ideal location, 15yrs
- Proposed site >10,000 Average Daily Traffic count on >30 acres



Greenland Meadows

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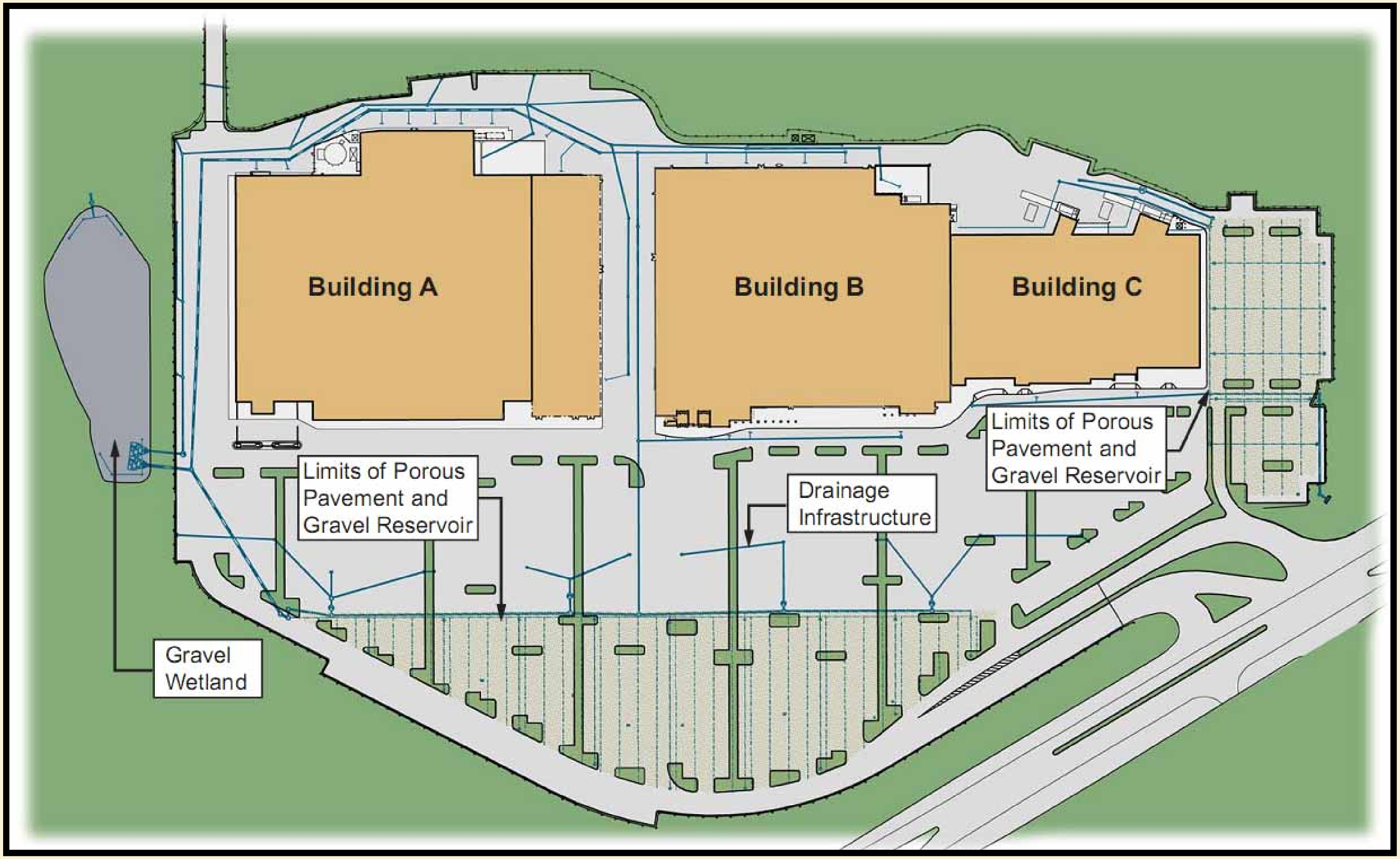
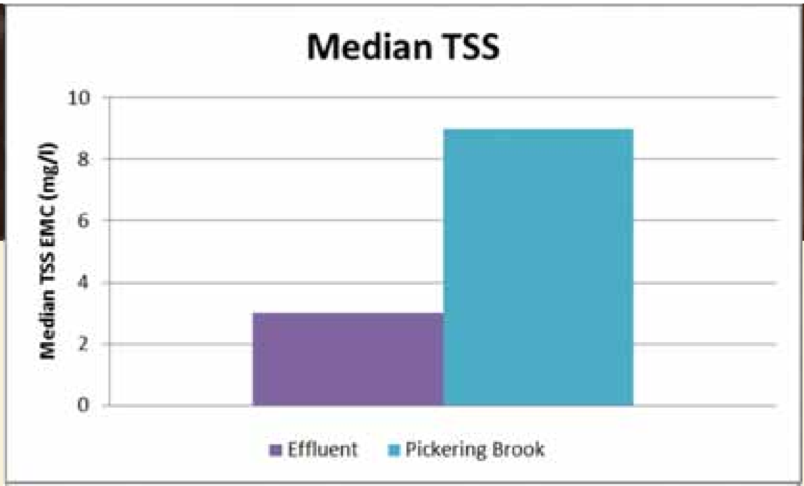
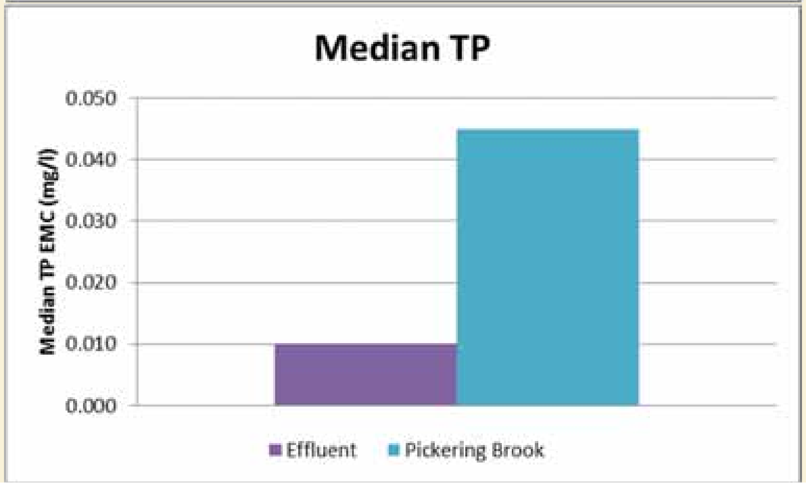


Comparison of Unit Costs

Item	Conventional Option	LID Option	Cost Difference
MOBILIZATION / DEMOLITION	$555,500	$555,500	$0
SITE PREPARATION	$167,000	$167,000	$0
SEDIMENT / EROSION CONTROL	$378,000	$378,000	$0
EARTHWORK	$2,174,500	$2,103,500	–$71,000
PAVING	$1,843,500	$2,727,500	$884,000
STORMWATER MANAGEMENT	$2,751,800	$1,008,800	–$1,743,000
ADDITIONAL WORK-RELATED ACTIVITY (utilities, lighting, water & sanitary sewer service, fencing, landscaping, etc.)	$2,720,000	$2,720,000	$0
PROJECT TOTAL	$10,590,300	$9,660,300	–$930,000





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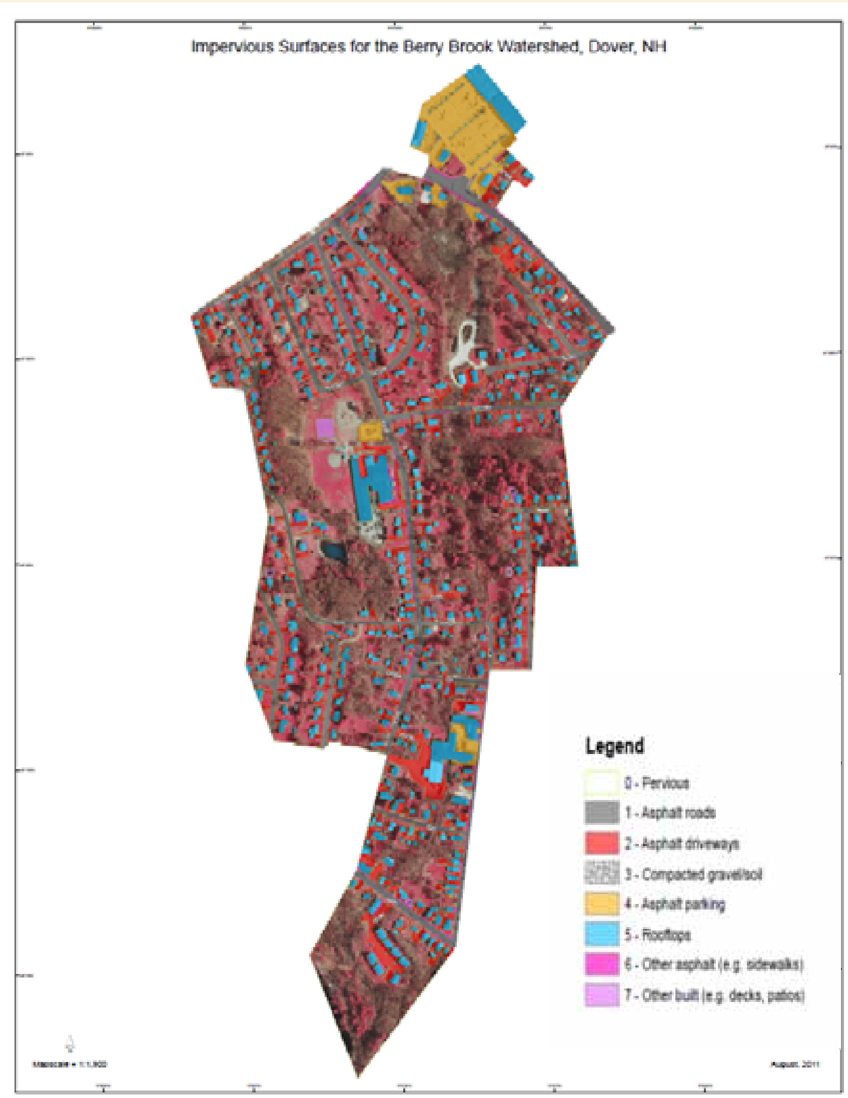
Watershed Level Case Studies

Berry Brook Watershed Overview
Impervious Surfaces



Surface	Area (acres)
Total Watershed	185
Pervious	129.4
Impervious Total	55.3 (30%)

Source: Adapted from Mapping Impervious Surfaces in the Berry Brook Watershed Complex Systems Research Center, August, 2011

Inside Slow Sand Filter

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Demolition

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Wetland Outlet Structure

Construction of Step-Pools

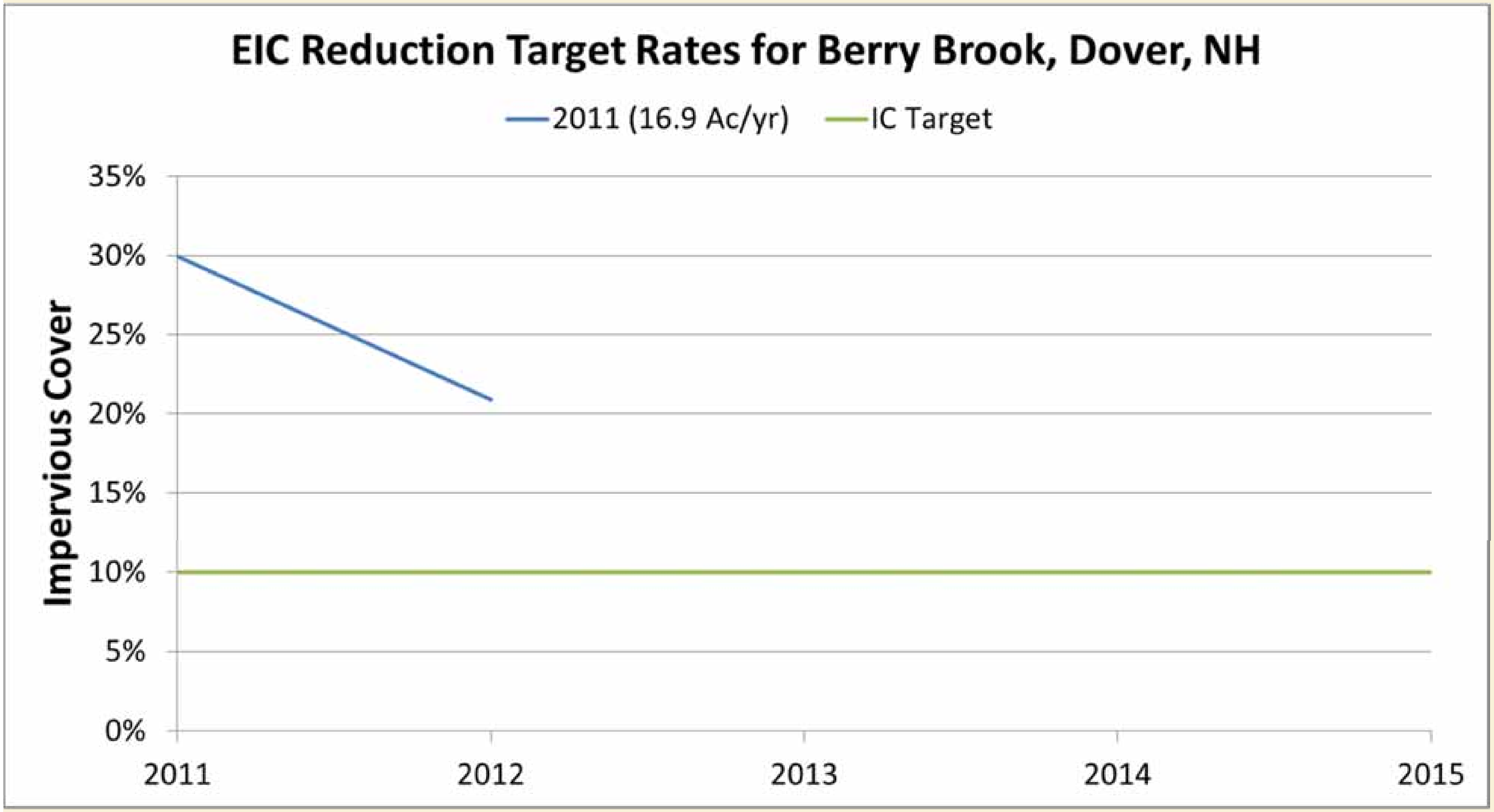
Walls at Tightest Floodplain


CLEAN WATER SOLUTIONS:


CAT

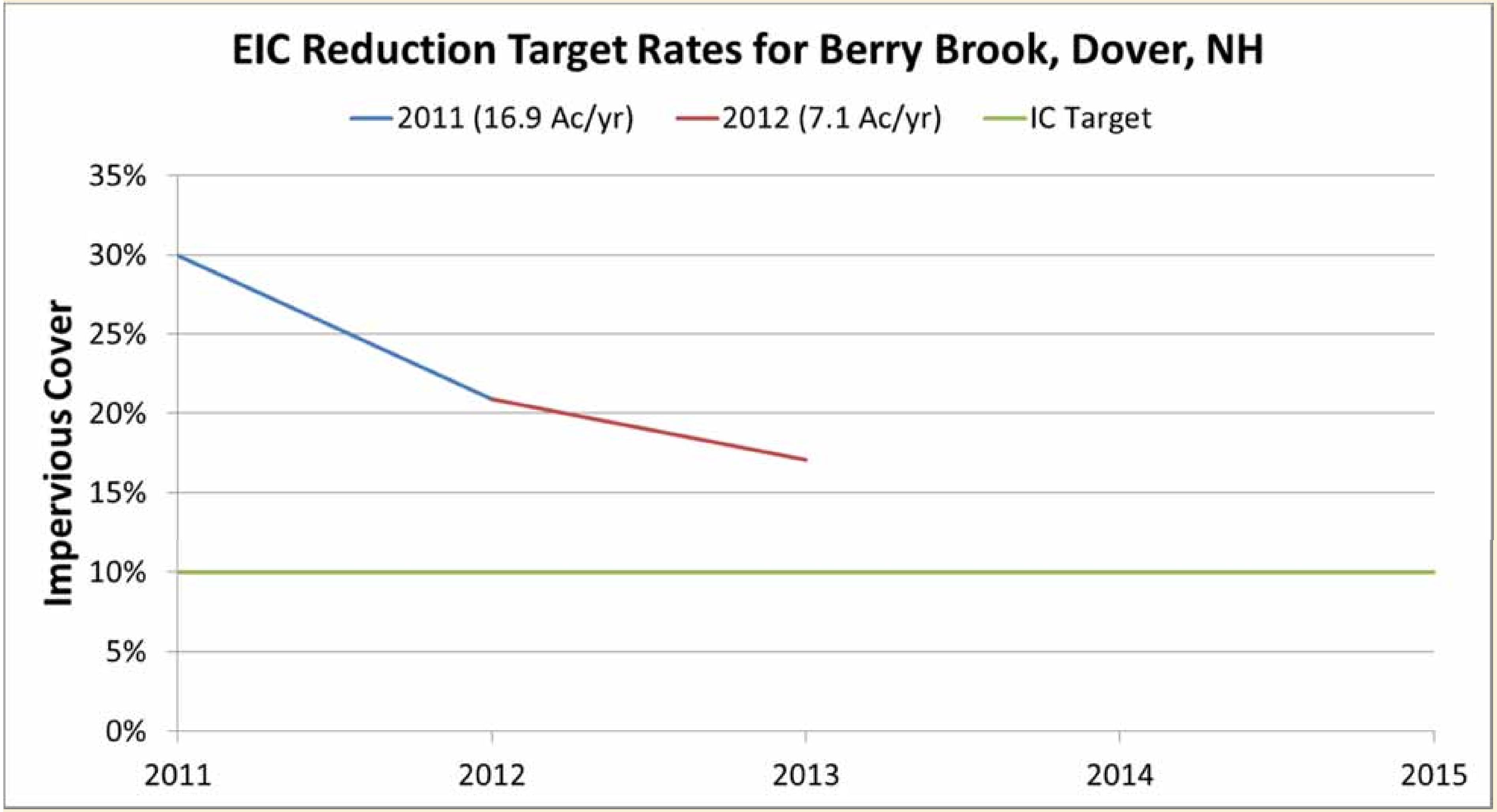
Part of the Solution – Watershed approach all communities can access

Berry Brook



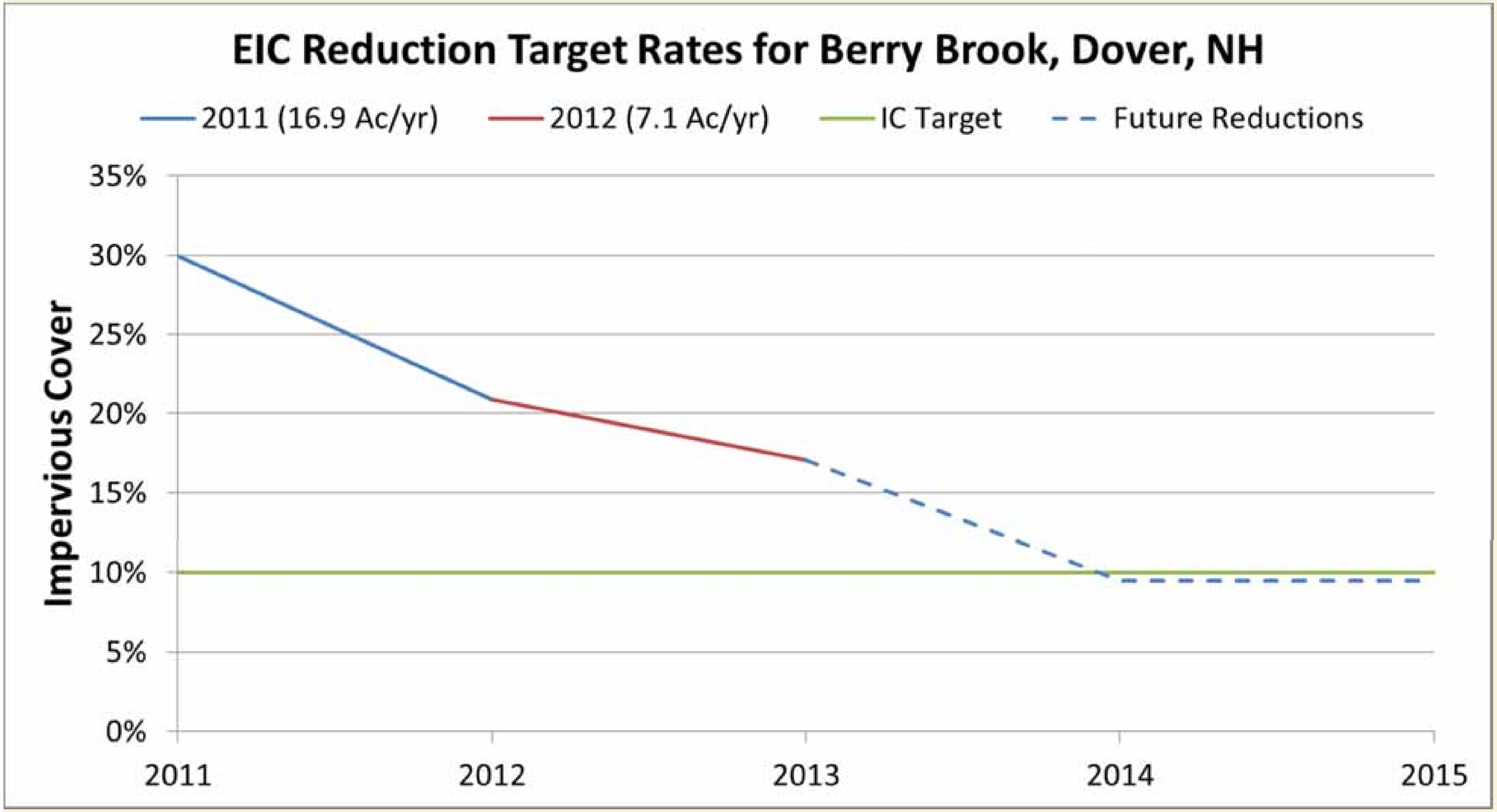
EIC Reduction Target Rates for Berry Brook, Dover, NH
2011 (16.9 Ac/yr)
IC Target
Impervious Cover
35%
30%
25%
20%
15%
10%
5%
0%
2011
2012
2013
2014
2015

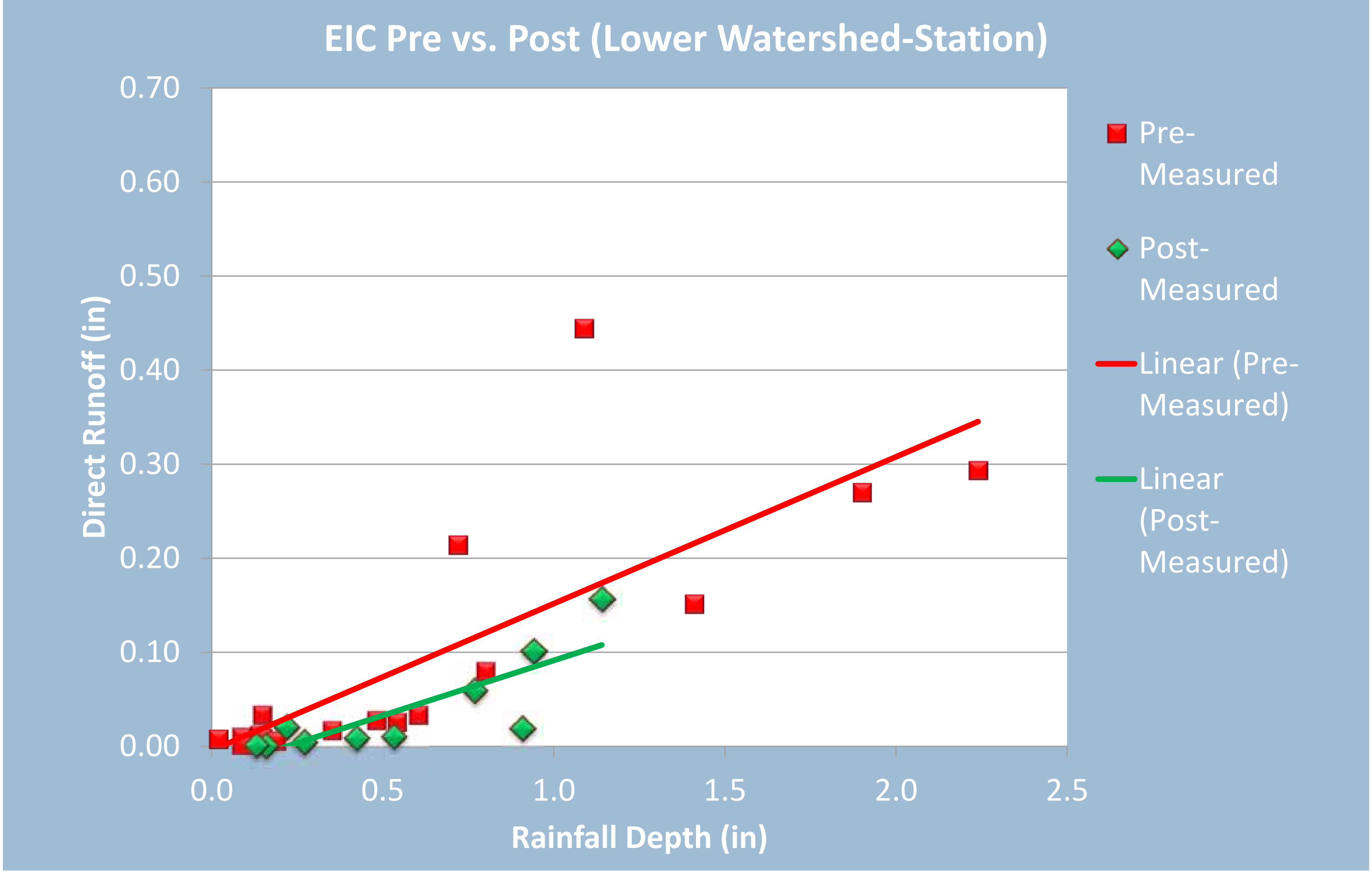
Berry Brook



EIC Reduction Target Rates for Berry Brook, Dover, NH
2011 (16.9 Ac/yr)
2012 (7.1 Ac/yr)
IC Target
Impervious Cover
35%
30%
25%
20%
15%
10%
5%
0%
2011
2012
2013
2014
2015

Berry Brook


EIC Reduction Target Rates for Berry Brook, Dover, NH
2011 (16.9 Ac/yr)
2012 (7.1 Ac/yr)
IC Target
Future Reductions
Impervious Cover
35%
30%
25%
20%
15%
10%
5%
0%
2011
2012
2013
2014
2015



EIC Pre vs. Post (Lower Watershed-Station)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Direct Runoff (in)
0.0
0.5
1.0
1.5
2.0
2.5
Rainfall Depth (in)
Pre-Measured
Post-Measured
Linear (Pre-Measured)
Linear (Post-Measured)
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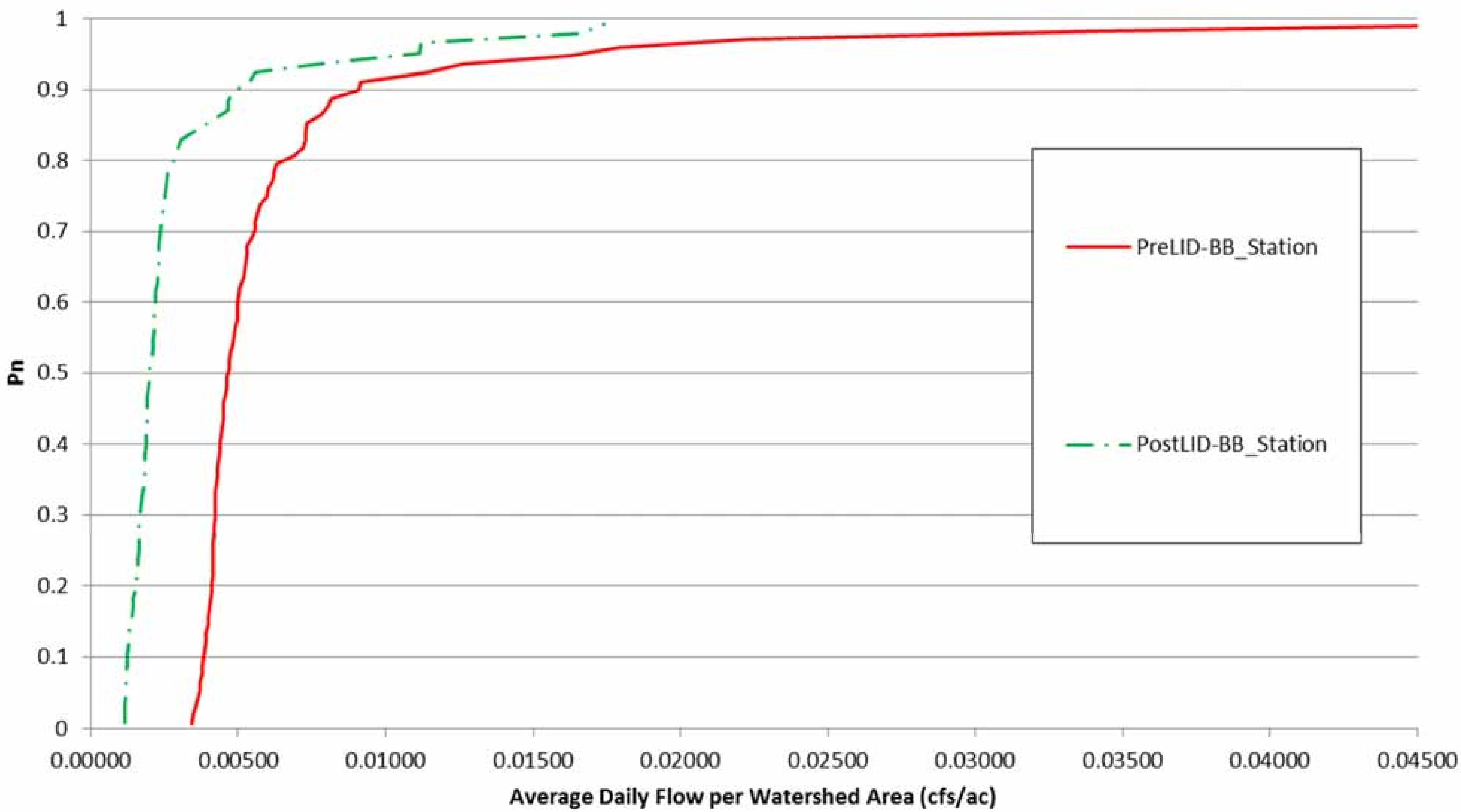
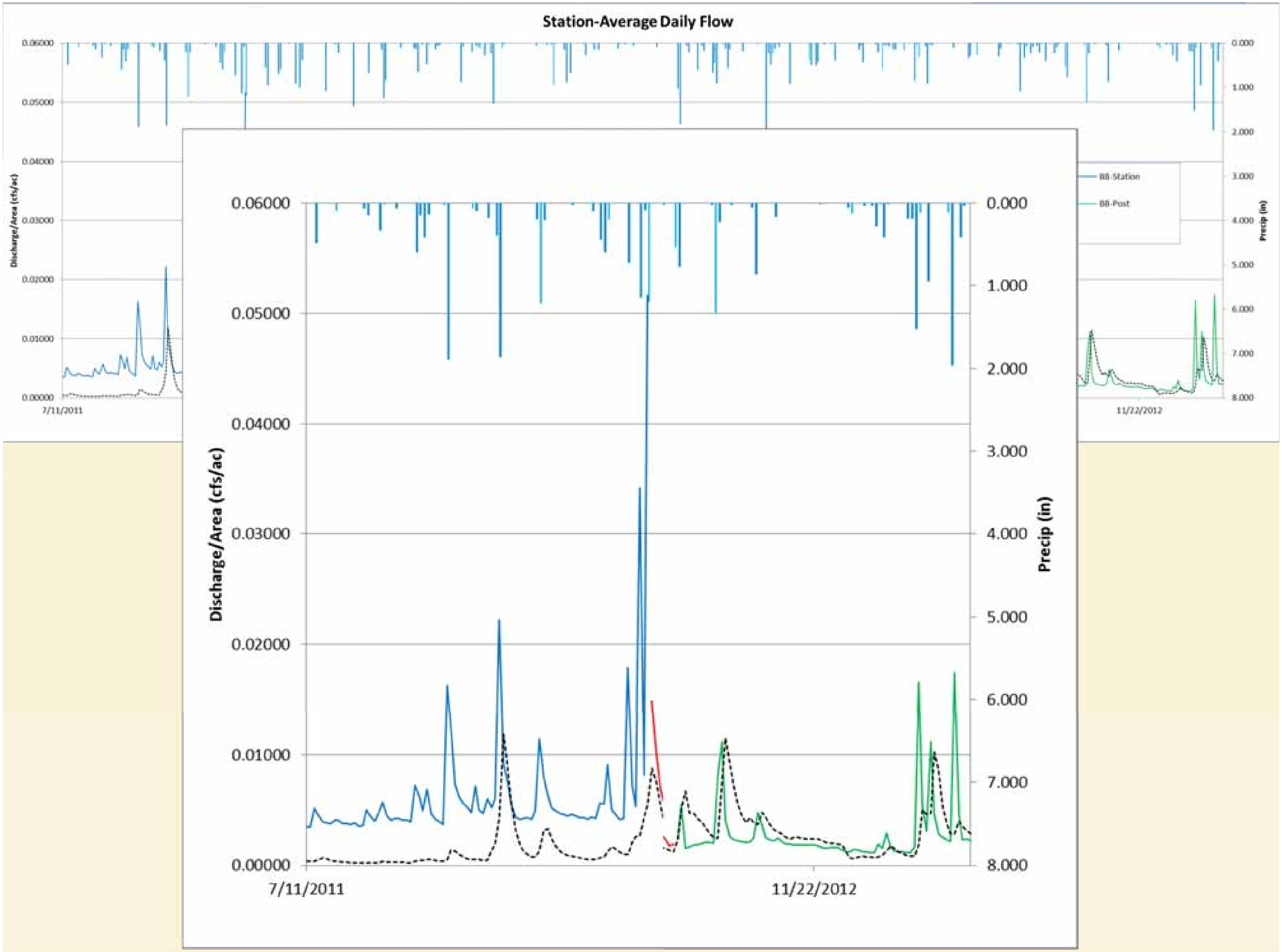
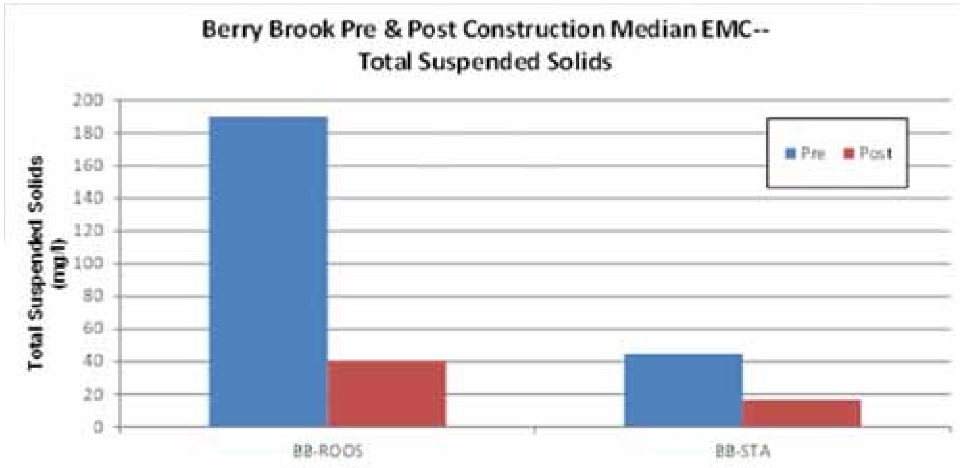
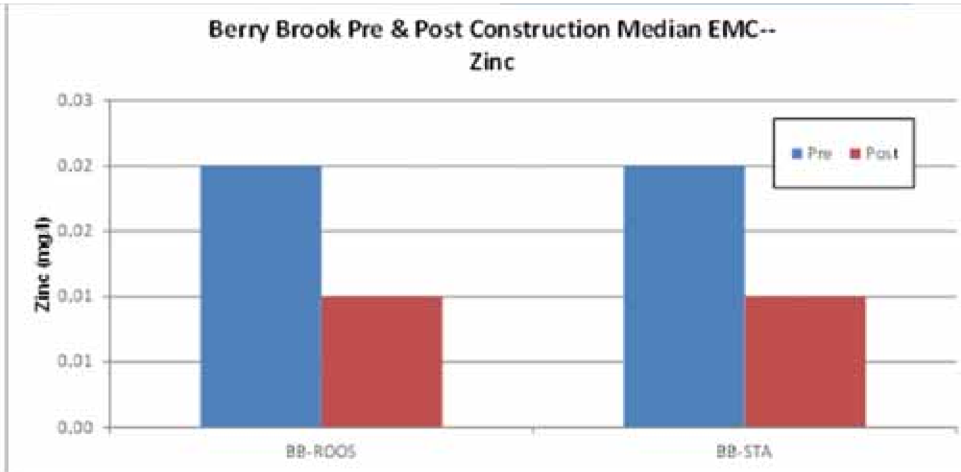
Flow Duration Cuves by Time Period

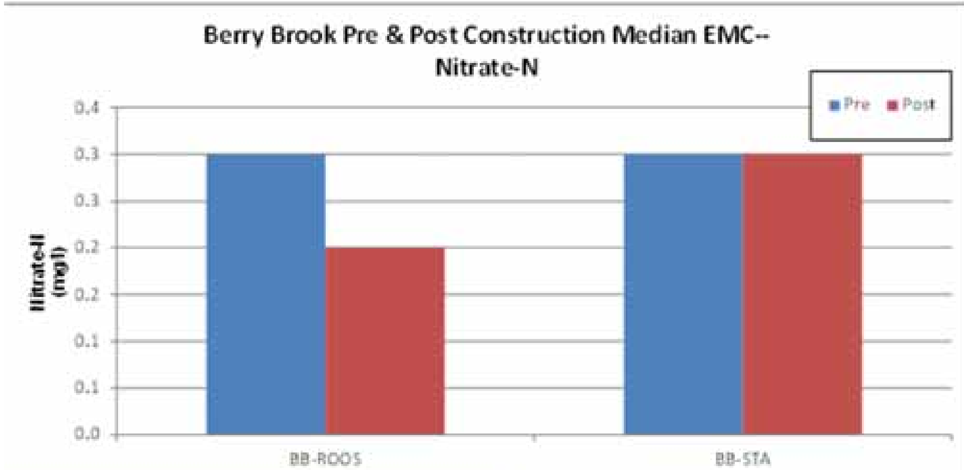


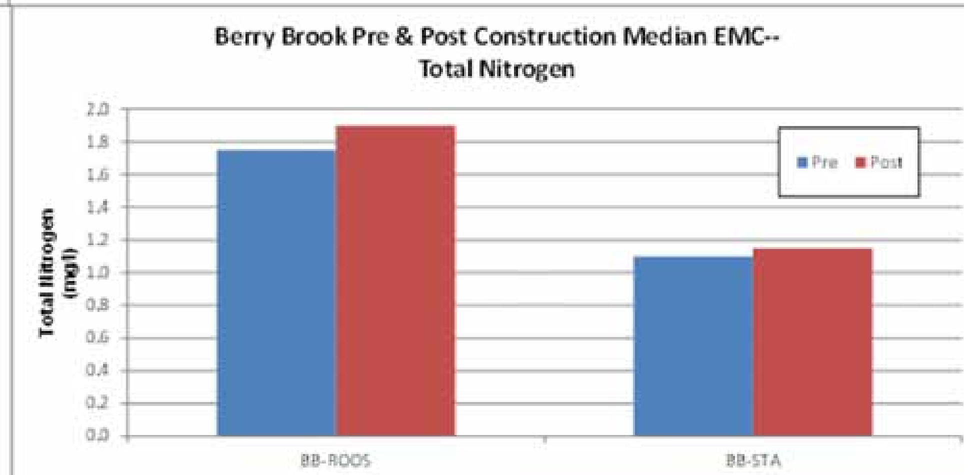


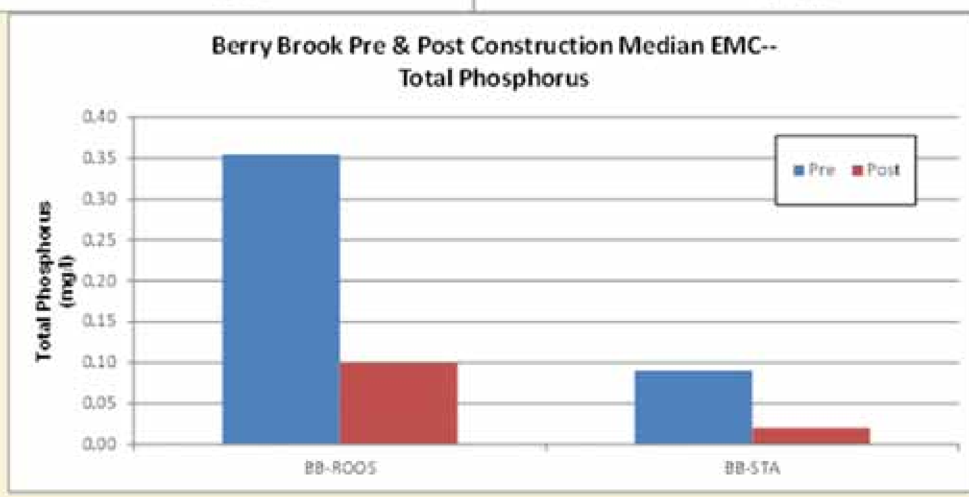
Station-Average Daily Flow
Discharge/Area (cfs/ac)
Precip (in)
BB-Station
BB-Post
0.06000
0.05000
0.04000
0.03000
0.02000
0.01000
0.00000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
7/11/2011
11/22/2012


Berry Brook Pre & Post Construction Median EMC--
Total Suspended Solids
Total Suspended Solids (mg/l)
200
180
160
140
120
100
80
60
40
20
0
Pre
Post
BB-ROOS
BB-STA


Berry Brook Pre & Post Construction Median EMC--
Zinc
Zinc (mg/l)
0.03
0.02
0.02
0.01
0.01
0.00
Pre
Post
BB-ROOS
BB-STA


Berry Brook Pre & Post Construction Median EMC--
Nitrate-N
Nitrate-N (mg/l)
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
Pre
Post
BB-ROOS
BB-STA


Berry Brook Pre & Post Construction Median EMC--
Total Nitrogen
Total Nitrogen (mg/l)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Pre
Post
BB-ROOS
BB-STA


Berry Brook Pre & Post Construction Median EMC--
Total Phosphorus
Total Phosphorus (mg/l)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Pre
Post
BB-ROOS
BB-STA

Interim Results

- **EIC is approximating predevelopment hydrology – we are moving toward hydrologic transparency!**

- **Data supports the use of EIC in general as a predictor of watershed health (strong for hydrology, developing for chemistry and aquatic health)**

- **Need more monitoring**

- **IC disconnection as a surrogate for water quality seems to be a very effective measure**

Maintenance

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1,000 Pound Gorilla

Who has primary responsibility for maintenance?

- local governments or public agencies?
- States and the Federal Governments?
- Private property owners and associations?

What is Maintenance

- Often Maintenance only occurs when there is failure
- There is a perception that LID systems require more maintenance
- Conventional practices have a high degree of failure and significant cost impacts—however we are familiar with it

Conventional Systems

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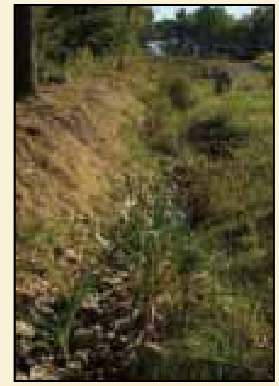
Detention Basin

Retention Pond

Stone Swale



Veg Swale

Low Impact Development Systems

Porous Asphalt

Gravel Wetland

Sand Filter

Bioretention Unit (3)

Maintenance Complexity is defined as:

Minimal	Simple
Stormwater Professional or Consultant is seldom needed	Stormwater Professional or Consultant is occasionally needed
Moderate	**Complicated**
Stormwater Professional or Consultant is needed half the time	Stormwater Professional or Consultant is always needed

Erickson, et al, 2010

Reactive

Episodic maintenance, cheap in short term, expensive in the long term

Periodic/Predictive

Science basis, schedulable activities, more cost effective

Proactive

Cost effective, preventative operations

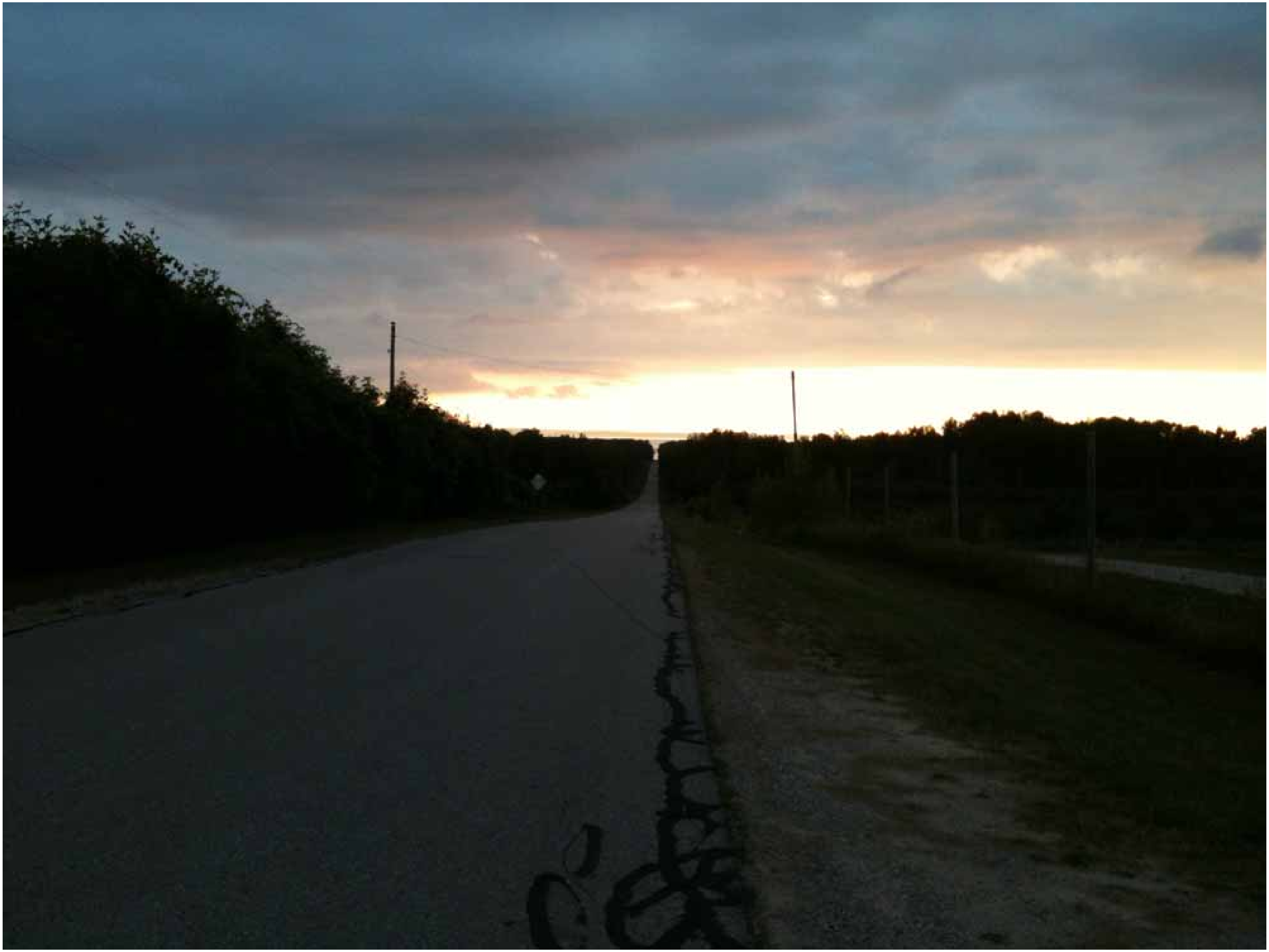
+

($)

-

Adapted from Reese, A.J., Presler, H.H., 2005

But we design things to be low maintenance!




Brian

Tools of the trade…

Tools of the trade…

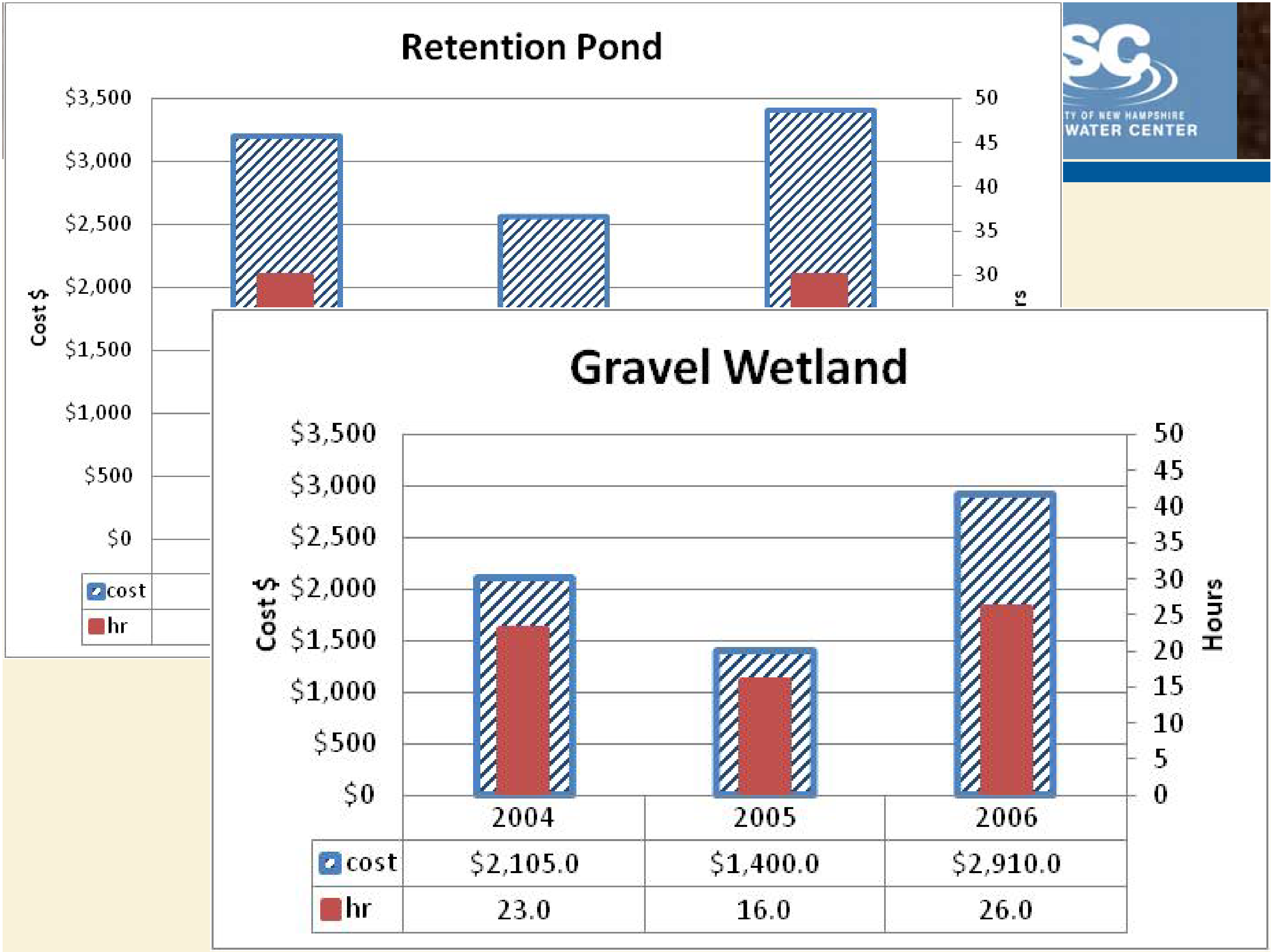
Tools of the trade…

Components of a best-case scenario:

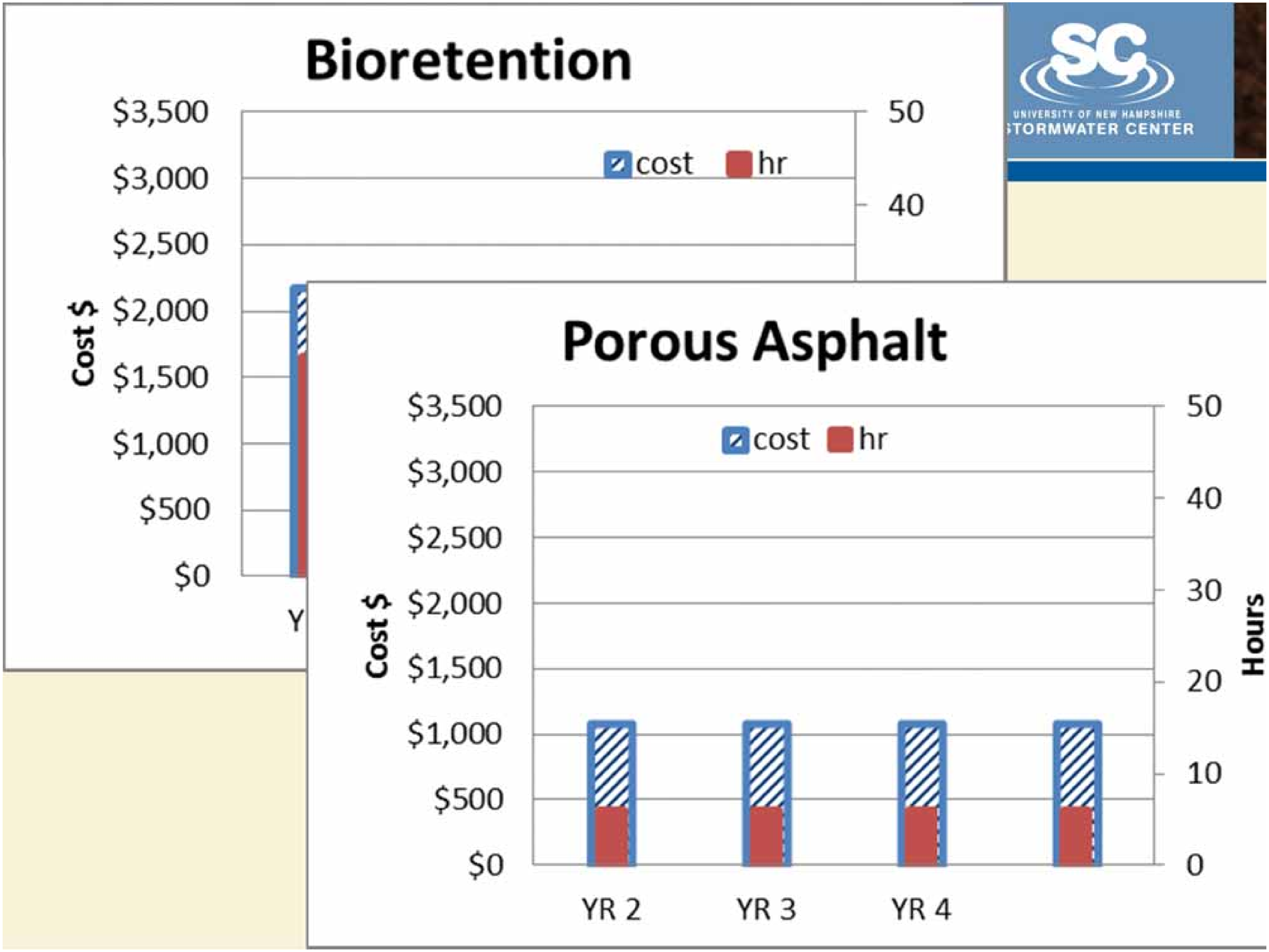
1. Appropriate Design

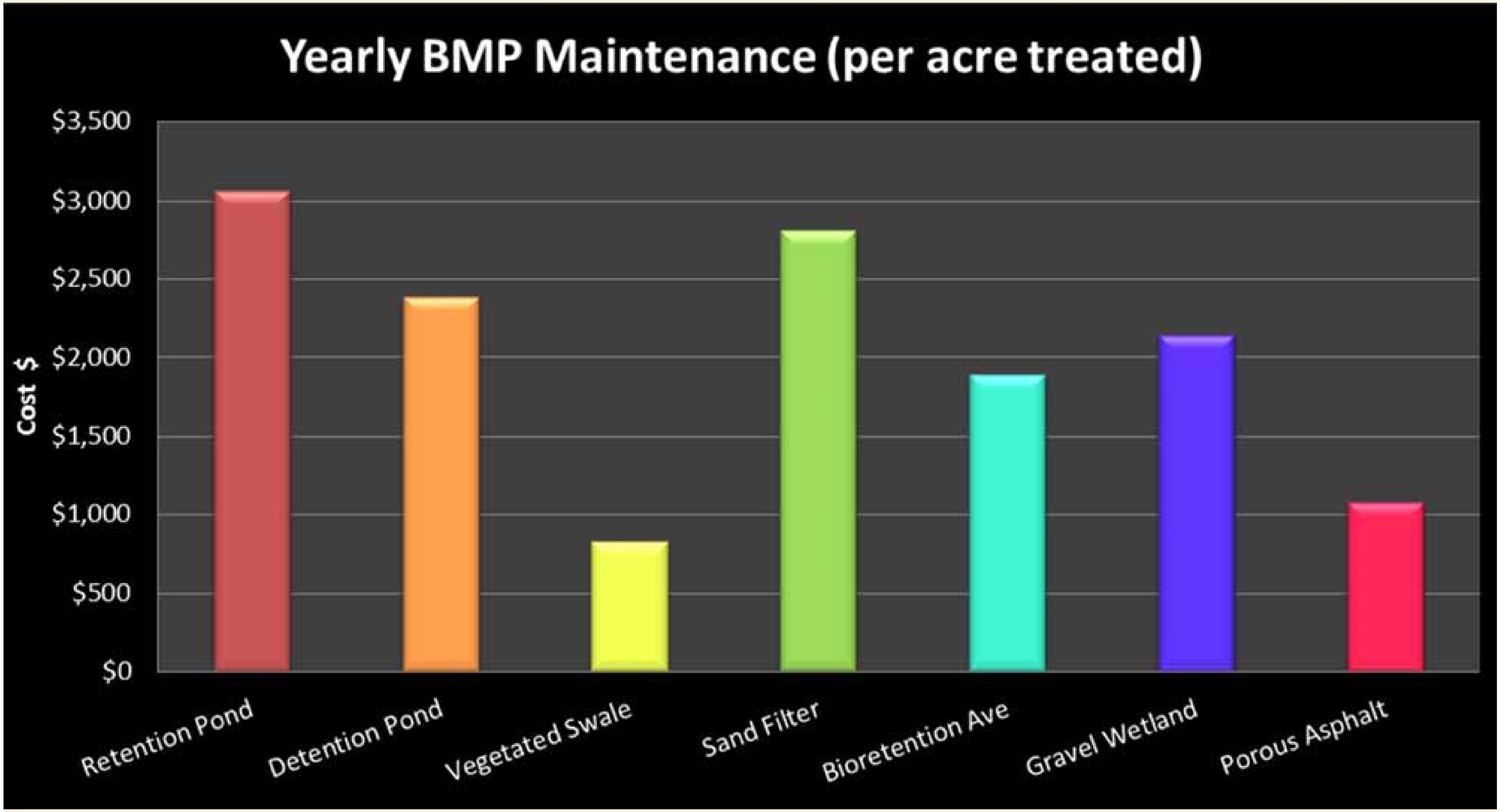
2. Installation

…. Then Maintenance



Retention Pond
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
cost
hr
Gravel Wetland
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
25
20
15
10
5
0
Hours
2004
2005
2006
cost
$2,105.0
$1,400.0
$2,910.0
hr
23.0
16.0
26.0
WATER CENTER


Bioretention
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
40
cost
hr
UNIVERSITY OF NEW HAMPSHIRE
Porous Asphalt
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
40
30
20
10
0
Hours
cost
hr
YR 2
YR 3
YR 4



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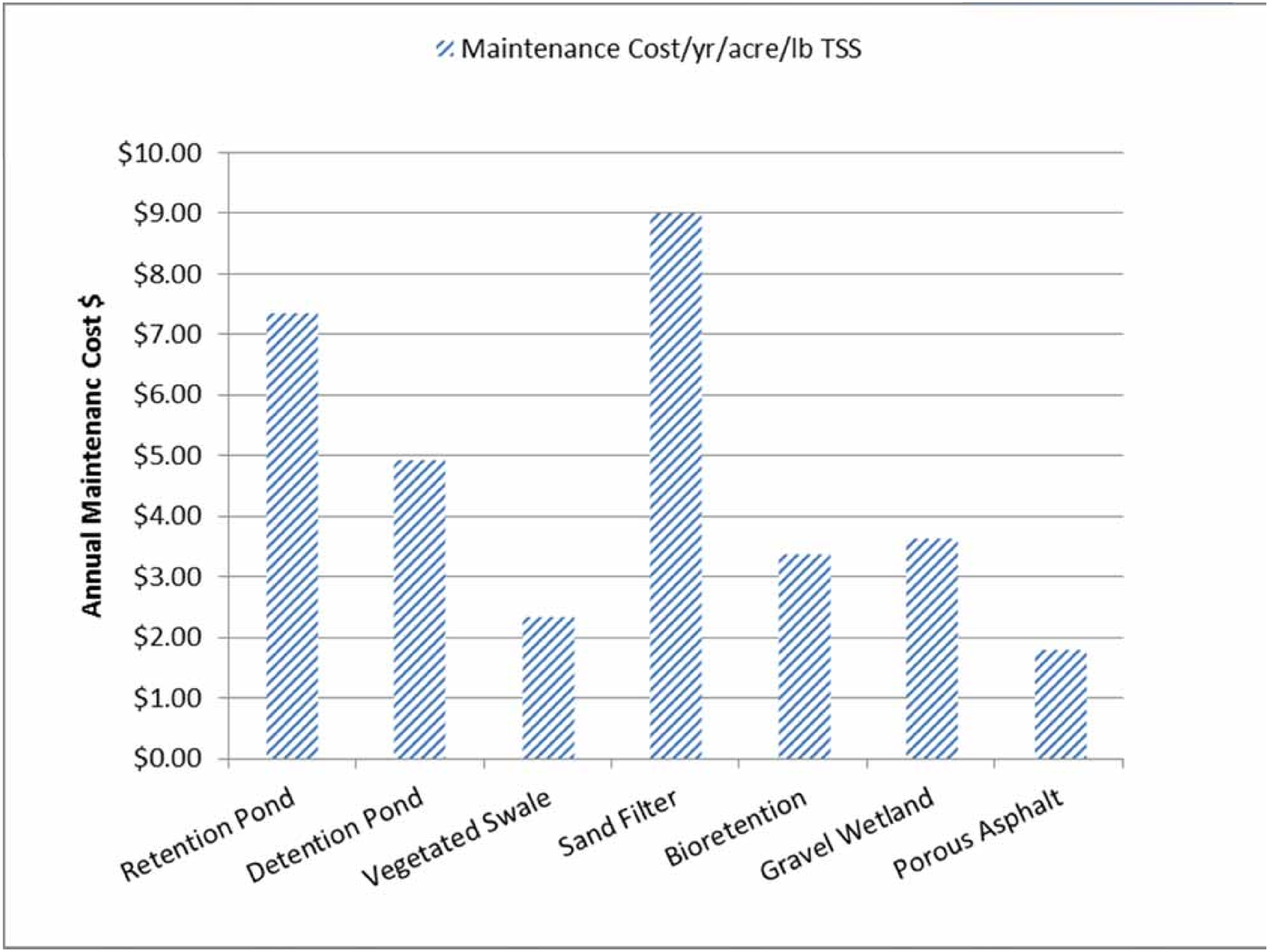
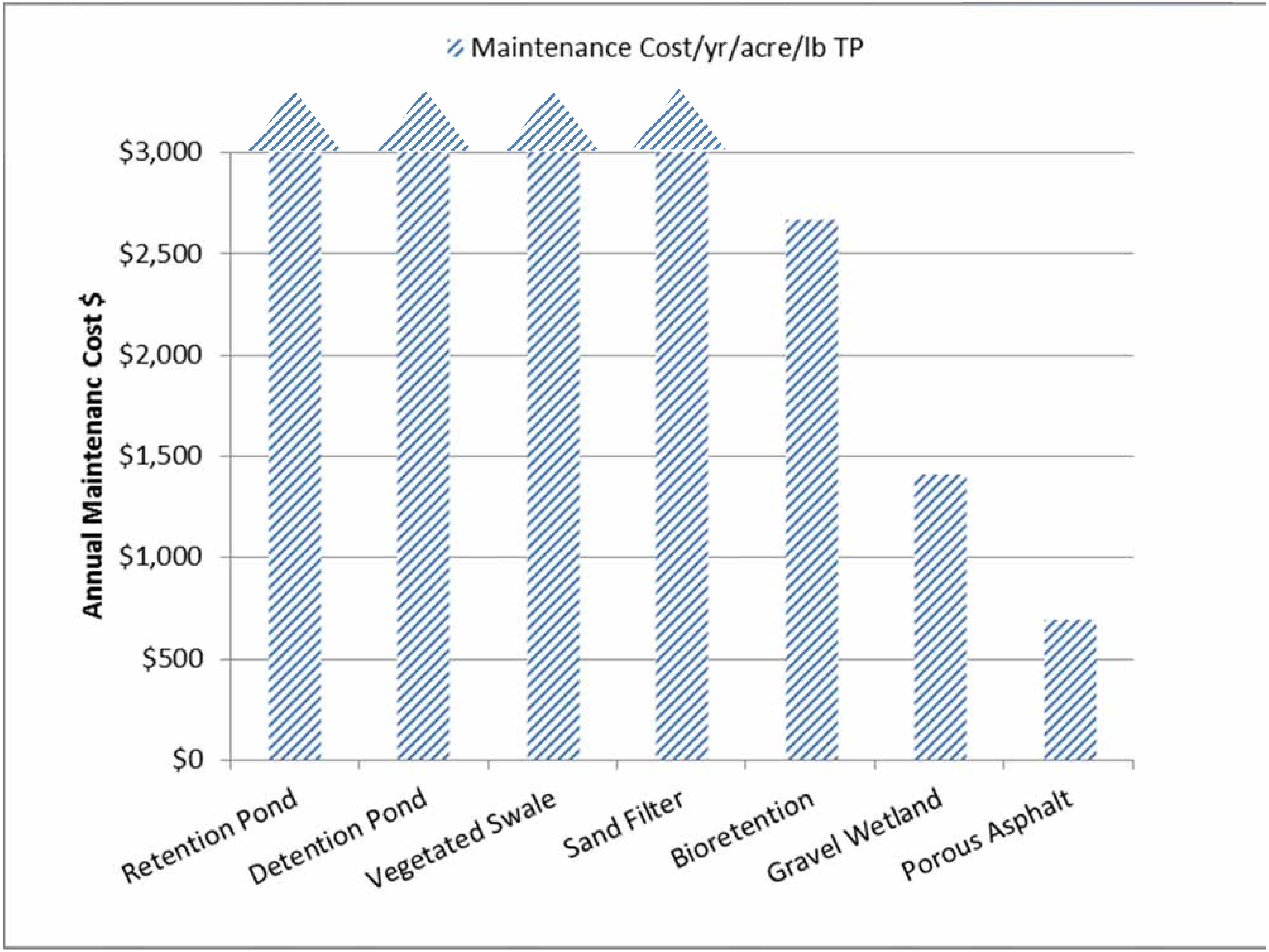
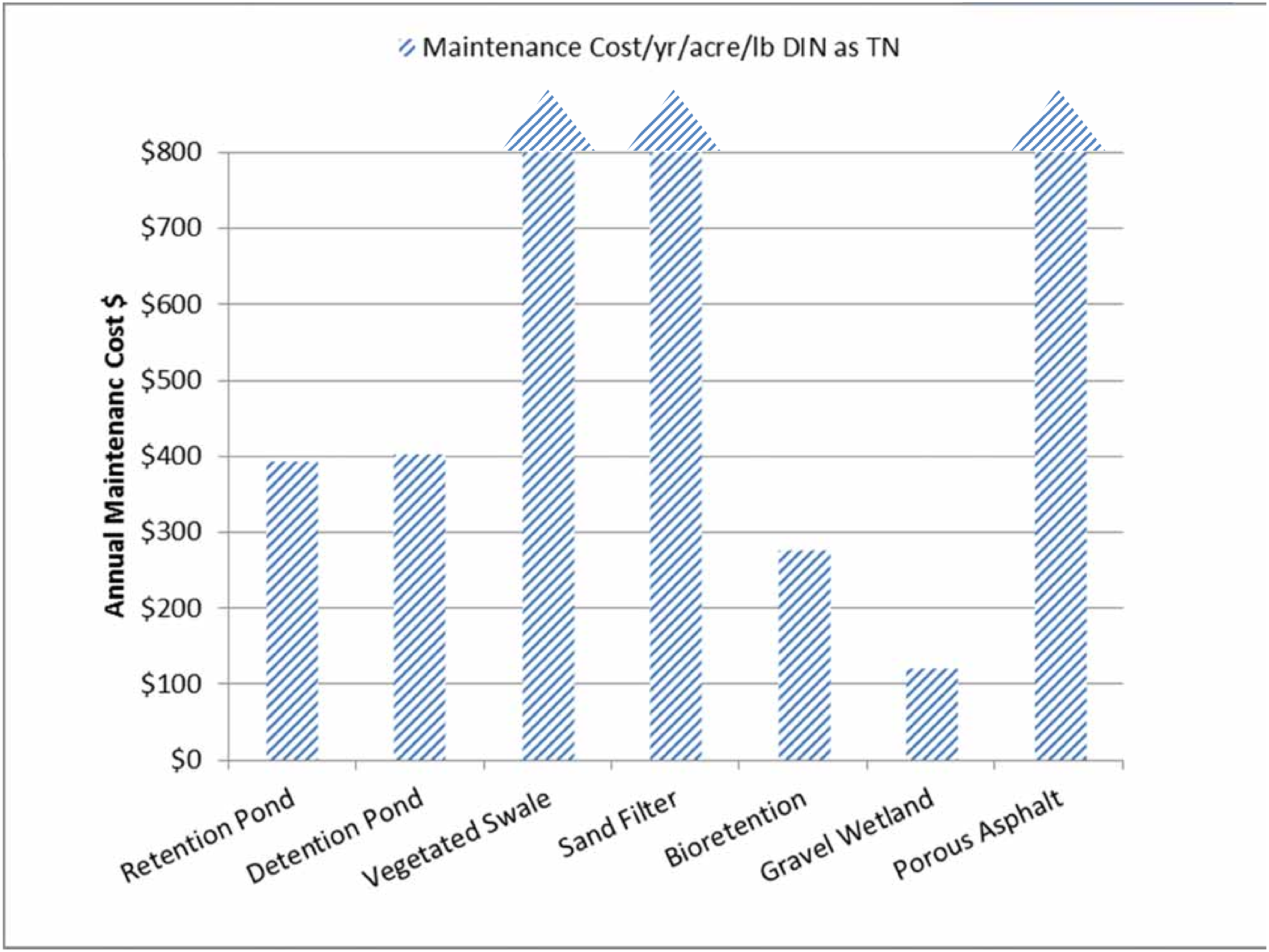
Economics of Installation vs Maintenance Costs, normalized by area

Parameter	Vegetated Swale	Wet Pond	Dry Pond	Sand Filter	Gravel Wetland	Bioretention	Porous Asphalt
Capital Cost ($)	12,000	13,500	13,500	12,500	22,500	21,550	21,800
Inflated 2012 Capital Cost	14,600	16,500	16,500	15,200	27,400	25,600	26,600
Maintenance and Capital Cost Comparison	17.8	5.4	6.9	5.4	12.8	13.5	24.6
Personnel (hr/yr)	9.5	28.0	24.0	28.5	21.7	20.7	6.0
Personnel ($/yr)	823	3,060	2,380	2,808	2,138	1,890	380
Subcontractor Cost ($/yr)	0	0	0	0		0	700
Total Operational Cost ($/yr)	823	3,060	2,380	2,808	2,138	1,890	1,080
Operation/Capital Cost (%)	6%	19%	14%	18%	8%	8%	4%


Maintenance Cost/yr/acre/lb TSS
Annual Maintenanc Cost $
$10.00
$9.00
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt



Maintenance Cost/yr/acre/lb TP
Annual Maintenanc Cost $
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt



Maintenance Cost/yr/acre/lb DIN as TN
Annual Maintenanc Cost $
$800
$700
$600
$500
$400
$300
$200
$100
$0
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt

A tale of two raingardens

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Maintenance solved?

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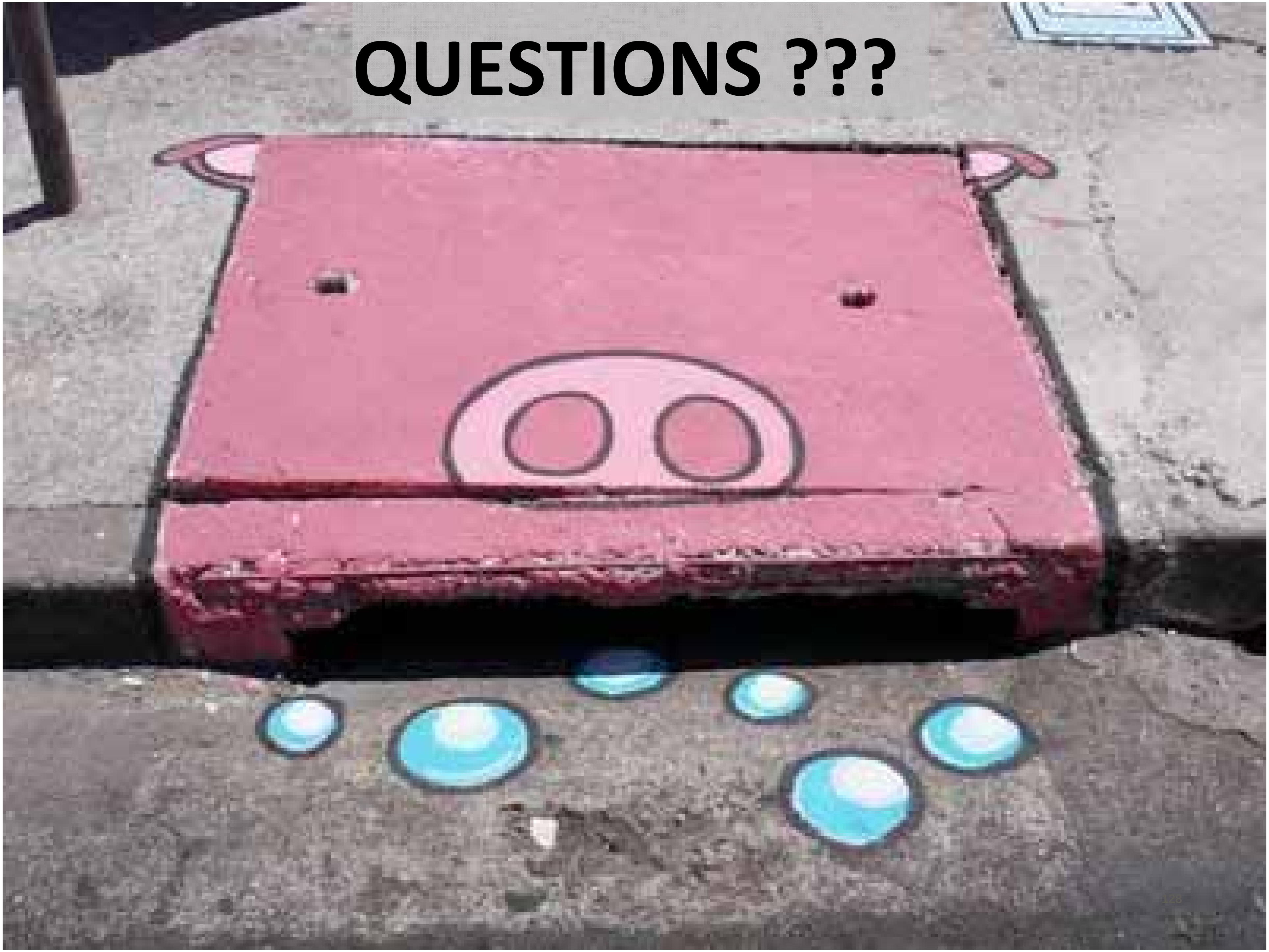
QUESTIONS ???